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ABSTRACT

This module provides information about 14 existing land application systems. Each case study gives the location and description of the system, volume treated, climate and soil type, cost, land area, and other data. A brief comment about the system is given as well as a more detailed discussion. References are cited which may be used to examine 100 or more other sites. (Author/BE)

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Land Application of Wastes

An Educational Program

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LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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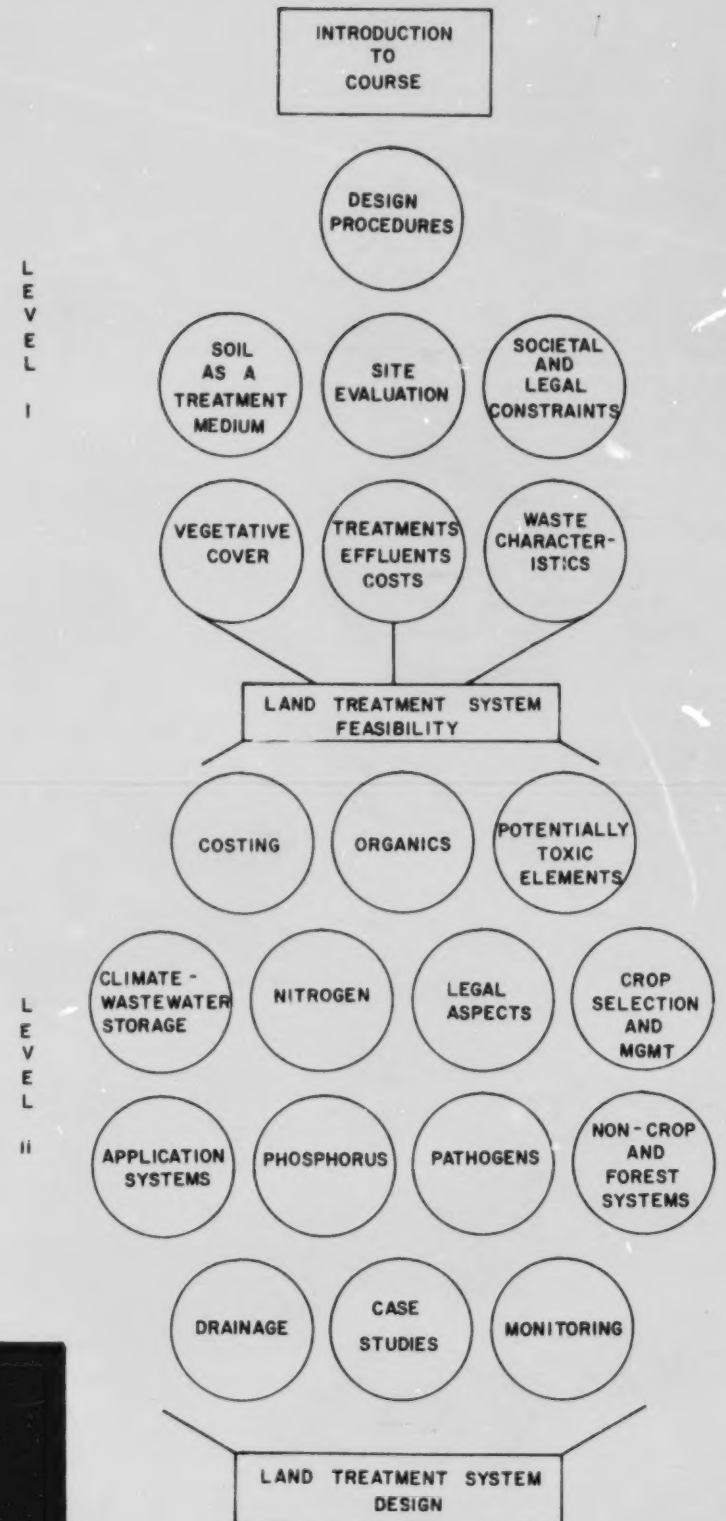

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CASE STUDIES REVIEWED

Module 14

January, 1978

Summary

This module provides information about 14 existing land application systems. References are cited which may be used to examine 100 or more other sites.

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Objectives

Upon completion of this module the reader should be able to:

1 Use the information given in this module or in the referenced literature to supplement the ideas and insights expanded on in other modules.

2 Use the basic format of this module to build up a private library of abstracts of land application systems.

3 Arrive at a number of specific, pertinent questions that should appear in every report of land application systems, and evaluate reports in terms of the adequacy or inadequacy of each report.

Introduction

This module is a compendium of descriptions of 14 land application sites in the United States and abroad. It is designed as background information for group discussions and as a reference of specific examples to illustrate basic concepts of land treatment.

It is not always easy for readers to determine how various ideas expressed in this course blend together and work in a real system. Therefore, this module is designed to review real land application systems and to give the participants an opportunity to evaluate these systems in relation to the information given in other modules.

As shown in Figure 1, there are more than 360 land application systems in the United States and many more are in the planning stage. This is a conservative estimate. This module documents 14 of those sites, each site exemplifying a unique problem. Abstracts of those cases appear in this module. The bibliography gives sources of information for compiling similar abstracts on more than 100 land application sites. The reader may wish to expand this file of actual systems by consulting these references.

Probably the best single source of information on long-term use of land application technology is the publication Land Application of Sewage Effluents and Sludges: Selected Abstracts, compiled and published by the EPA. The abstracts are arranged in chronological groupings and cross-referenced. This reference contains a large number of interesting systems built prior to 1974. A short summary of recent systems built between 1973 and 1976 entitled "Selected Recent Reports on Land Application of Municipal Wastewaters", is available from the EPA. The

Figure 1. Locations of the more than 360 land application sites in the United States.

1973 report Survey of Facilities Using Land Application of Wastewater is also useful. It contains some general discussion of the techniques involved as well as case histories of domestic and industrial applications.

Figure 2 illustrates the general climatic zones of the United States which are used in each case history description in this module. Reference to this climatic data is included in the "Case Study Cover Sheet" which introduces each of the fourteen examples. Where foreign sites are documented, an attempt has been made to relate these sites to the domestic climatic zones of Figure 2.

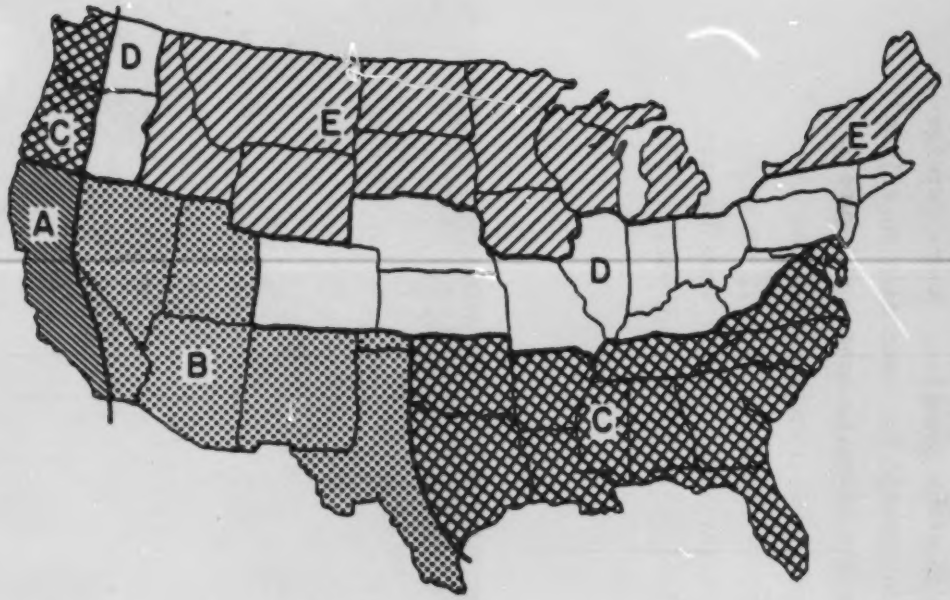

Figure 2. The United States is divided into five general climate zones useful in planning land application systems (after Pound and Crites, 1973).

CASE STUDY COVER SHEET

SYSTEM Werribee Farm System (Name) 1897 (Date started)

LOCATION Melbourne, Australia (Person involved)

FACILITY DESCRIPTION raw sewage (waste classification) flood irrigation & overland flow (application system(s))

APPLICATION 4 in./day; Total 44 in/yr; 1 day apply, 17-19 day rest (rate) (schedule)

CROP(S) Pastureland grasses: Cattle, sheep, some horses

PRETREATMENT Screening

VOLUME TREATED 150 mgd

WORKING YEAR 12 mo. CLIMATE ZONE similar to D

SOIL Silt-clay loam

COST U.S. $1.53 (per capita) per year

LAND AREA 27,000 acre

STORAGE CAPACITY

COMMENT: Old and very successful land application system handling large volumes of raw sewage. No health problems to animals or 17 families residing in area. Animal sales bring good income. Odor problems are encountered as system suffers urban encroachment. Not a research project but has 31 test wells and specific monitoring schedule for water and livestock. Soils and vegetation are monitored occasionally. Operates as flood irrigation in summer, overland flow in winter. Increasing use of aerobic and anaerobic lagoons for wastewater treatment in recent years due to limitation in available land area, and encroaching urbanization.

REFERENCES: Seabrook, B.L. 1975. Land application of wastewater in Australia. The Werribee farm system. Prepared for U.S. EPA Municipal Construction Division, Office of Water Program Operations (May). 27 p.

(continued on next page)

CASE STUDY COVER SHEET (continued)

Johnson, R. D., R. L. Jones, T. D. Hinesly, D. J. David. 1974. Selected chemical characteristics of soil, forage and drainage water from the sewage farm serving Melbourne, Australia. Prepared for the Dept. of Army Corps of Engineers. 54 p.

Searle, S. S. and C. F. Kirby. 1972 (fall). Waste into wealth. Water Spectrum, U.S. Army Corps of Engineers. 15-21.

Werribee Farm System
Melbourne, Australia

The land application system serving Melbourne, Australia covers over 17,000 acres. Although highly successful for more than 75 years, the system is being encroached upon by urban development. Pretreatment and lagooning of some waste flow is now being employed to decrease the land area required for treatment.

The Werribee Farm System is one of seven sewage treatment facilities serving Melbourne, Australia. It is widely known as a large scale land application system that had handled raw municipal sewages for more than seventy five years. Until the mid 1970's, 95% of the sewered effluent of Melbourne went to the Werribee Farm. Melbourne officials are very satisfied and seek to use land application in connection with as many of their facilities as possible. Urban sprawl, however, is decreasing available lands so secondary pretreatment is used to decrease needed acreage for other sites. Of the 27,000 acres, 17,000 acres are used for some form of waste treatment. The facility is predominantly permanent pastures with some three quarters of its land doubling as wild bird preserves. The remaining 10,000 acres are used for roads, houses, animal and machinery shelter, dry grazing, yards and other purposes.

Each pasture is 20 acres and is divided into 50 bays by low check banks, subsoiled, graded, and sown with selected grasses (Johnson, et al., 1974). The grasses are grazed by 20,000 cattle and 10,000 sheep. Summer application consists of flooding 600 acres of bays daily to 4 inches, then allowing a 17-19 day "rest" period. The organic load averages about 30 lbs/acre-day BOD. The Werribee Farm System is underdrained, and tiled effluent (high in K) is discharged into Port Phillip Bay. Shallow lagoon storage is being phased out. Winter treatment is by overland flow over 3,472 acres with excess being treated in 3,393 acres of anaerobic and aerobic lagoons. A schematic presentation of the system is given in Figure 3.

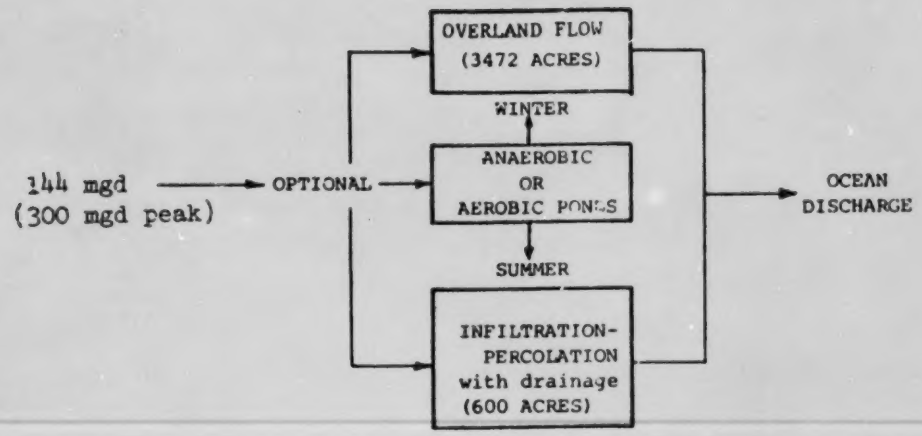

Figure 3. Schematic of the Melbourne, Australia wastewater treatment system.

Surface soil is slightly acid red-brown silty clay. Soil becomes calcareous at about 12 in. with clay:silt:sand being about 35:45:20. The C.E.C. of the 1-7" layer of control soil is 15 meq/100 g and 10-25 meq/100 g for sewage amended soil. Infiltration capacity is about 2 in. per day. About 144 mgd (peak flows up to 300 mgd) arrive at the Werribee Farm. Annual rainfall averages 19 in. of which 12.5 in. fall during the irrigation season. Evapotranspiration accounts for about 35.6 in. in the same period suggesting that about half of the annual application of 44 in. of sewage water is evaporated.

Animal sales return U.S. $675,000/year. Animals are government inspected before sale and rejection rates are less than or equal to rates of animals grazed on untreated pastures. Families living within the Werribee Farm area exhibit very good health records.

Analyses of soils and vegetation in 1924 and again in 1972 suggest that organic nitrogen in topsoils has increased from roughly 0.36% to 1.12% and phosphorus from roughly 0.08% to 0.175% (normal ranges for agricultural soils are 0.02-0.50%N and 0.01-0.40%P). Carbon content of irrigated topsoils has increased from 3.7% to 10.0%. At the same

time the C/N ratio of surface soils has decreased from about 13/1 to 10/1. The average pH of soils has decreased from 7.5 to 6.2 but ranges widely (1.1 to 8.4) in irrigated soils. N, C and P levels in subsoils are "normal". Mn, Fe, and Cr concentrations in the surface soil remain low. Pb is tightly bound in surface soils but its accumulated concentration has not exceeded the "normal range" in soils in any but one sampling site. Only at sites subjected to 60 and 73 years of application are Zn levels much above Zn content expected in normal soils, but even there Cu concentrations remain less than the normal maximum range of soil while Ni is well within the normal range. The zinc equivalent load of soils is about 8.5% of C.E.C., exceeding recommended levels (5% at pH > 6.5) even at lower pHs, but clinical symptoms of toxication are not apparent in vegetation.

Vegetation is known to take up N, P, and K from the sewage, but there is little or no change in Mg and Ca uptake. The resulting wider ratios (K/Ca and K/Mg) in forage leads to a condition known as grass tetany ("staggers" or hypomagnesia) in animals. This requires the addition of MgO to the dry hay fed to the animals. The sodium content of grasses appears to have increased the most, reaching values above those expected in irrigated grasses. Zinc and Cu levels in foliage tissues are at the high end of the normal range, with a few just exceeding that range. Cadmium contents barely exceed levels expected in the grasses and the Zn:Cd ratio values in grasses grown on plots irrigated for 60 and 73 years are 117:1 and 160:1 respectively. Lead content of foliage does not exceed normal values.

Water renovation was intended to reduce suspended solids to < 30 mg/l and BOD to < 20 mg/l to meet Australian standards of the late 19th century, and to this end the Werribee Farm has been successful. It

was not intended to achieve renovation equivalent to 1983 standards set for the United States. Nevertheless, 88% of N and 91% of P is removed from raw sewage. High K concentrations remain in the tile effluent, several times greater than the concentration of K in Port Phillip Bay. Nickel concentration is about 0.2 mg/l. From 78% to 91% of Zn, Cd, Cr, and Pb is removed and Cu concentrations are reduced to less than that of sea water.

Odors remain a real problem. The odors are not oppressive: The families who chose to live within the Werribee Farm Area testify to that. But modern urbanites make unhappy neighbors for the Werribee Farm, and odor is their objection. Clearly, if raw sewage is to be treated by land application, the site will have to be remote. The alternative is to introduce pretreatment, perhaps even secondary treatment as Melbourne is beginning to do, to eliminate the odors.

As residential development increases near the Werribee Farm overland flow treatment site, odor becomes more of a problem. The system is changing from application of raw sewage to application of pretreated sewage, even up to secondary treatment.

CASE STUDY COVER SHEET

SYSTEM Cape Cod Water Renovation and Retrieval System (Name) — 1973 (Date started)

LOCATION Otis Air Force Base, Cape Cod — Ralph C. Vaccaro (person involved)

FACILITY DESCRIPTION Municipal (waste classification) — Spray irrigation and infiltration (application system)

APPLICATION wide range of experimental variations (rate) — applying 1-3 in./wk (schedule)

CROP(S) reed canary grass, alfalfa, timothy

PRETREATMENT Imhoff-trickling filter

VOLUME TREATED 50,000 gallons per day (designed to treat 3.7 mgd)

WORKING YEAR 12 months CLIMATE ZONE D

SOIL unconsolidated gravel, sand and silt deposited by glacial outwash underlain by an impermeable consolidated bedrock roughly 260 ft below the surface

COST $500,000

LAND AREA 2.6 acres for irrigation 17 acres for sand filtration

STORAGE CAPACITY 0.3 MG

COMMENT: Objective is to evaluate alternative means of wastewater treatment and to develop design criteria for the recharge of water of potable quality to the groundwater reservoir of the coastal and outwash plains of Cape Cod and the Islands. Features a spray irrigation system wherein animal forage crops are used to remove nutrients and trace metals from secondary effluent. Additional attention is being given to the existing sand filter beds which, over the past 33 years have provided the traditional means of disposing of secondary effluent from the treatment plant at Otis. Extensive monitoring includes seven observation wells, nine groundwater sampling wells, suction lysimeters, soil analyses.

(continued on next page)

CASE STUDY COVER SHEET (continued)

REFERENCES:

Mann, A.W., R.F Vaccaro, P.L. Deese. Controlled chlorination in agricultural systems irrigated with secondary wastewater effluents. Journal of Water Pollution Control Federation. In press.

Mead, R. and R.F. Vaccaro. Sewage disposal in Falmouth, Massachusetts. III. Predicted effects of inland disposal and sea outfall on groundwater. J. Boston Society of Engineers 58(4): 278-297. 1971.

Kerfoot, W.B. and B.H. Ketchum. Cape Cod wastewater renovation and retrieval system, a study of water treatment and conservation. Technical Report WHOI 74-13, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. 1974.

Kerfoot, W.B., B.H. Ketchum, P. Kallio, P. Bowker, A. Mann, C. Scolieri. Cape Cod wastewater renovation and retrieval system, a study of water treatment and conservation, first year of operation. Technical Report WHOI 75-32, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. 1975.

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Cape Cod Water Renovation and Retrieval System
Otis Air Force Base, Cape Cod

The Otis Air Force Base waste treatment facility was built in 1942 to handle a 4 mgd flow. In 1973 Woods Hole Oceanographic Institute of Massachusetts began a research program centered on the Otis facility. In the original design, secondary effluent from a trickling filter was flooded onto 20 sand filter beds, but present loads require the use of only two filter beds at any one time on a rotational basis. One of the filter beds has been taken out of service and converted to a 0.3 MG capacity storage lagoon. The lagoon is the reservoir used to supply a newly installed spray irrigation system. The intention of the research project is to compare the extent of wastewater renovation by sand filters and spray irrigation of grasses and legume crops.

Secondary effluent from a trickling filter is flooded onto sand filter beds at the Otis Air Force base land application facility.

The waste application site includes a mass of unconsolidated gravel, sand and silt deposited by glacial outwash which is underlain by an impermeable consolidated bedrock roughly 260 ft below the surface. In a north-south direction, the bedrock remains level at an average depth of 170 ft below sea level. East of the site it dips to a depth of 400 ft below sea level.

Precipitation and its ultimate storage in groundwater is the sole source of fresh water on Cape Cod. An annual rainfall of about 2.14 million gallons per day per square mile, following transpiration losses, provides an estimated 1.07 million gallons per day per square mile to form a water table which reaches a maximum height of 60 ft above sea level north of Otis.

Spray irrigation plots have a surface layer of loam underlain by roughly a meter of Enfield sandy loam. Below 2 m depths, the topsoil grades from fine sandy loam to

medium sand. Deep geological cores indicate a substrate of medium to coarse sand with occasional cobblestone layers to the vicinity of bedrock 258 ft below the surface.

During the history of the sewage treatment plant, in operation since 1942, over 6 billion gallons of water have been discharged onto the sand filter bed system. The area of application which was served by gravity sand filtration totals 17 acres and is divided into 22 beds. At full operation of 3.7 mgd, the rate of application was 150,000 gallons per acre per day. Presently the Otis sewage treatment plant treats less than 50,000 gallons per day because of reduced personnel at the Otis base. Effluent is delivered to the filter beds by gravity mains and distributed by large wooden sluiceways. Cores taken from the beds show a layer roughly 1 ft thick of graded sand underlain by natural deposits of Enfield sandy loam and some silt deposits within the first few feet. At greater depths, 18 to 20 ft of medium sand and cobblestone occur down to groundwater level.

To evaluate a spray irrigation cropping program for wastewater management, the pilot facility was designed to provide year-round irrigation to test the water quality effects of a holding basin, to test prechlorination before irrigation, and to compare the performance of fixed versus rotary rigs for wastewater distribution. Two irrigation sites have been seeded with forage crops. Within Site A three subplots provide rates of application of 1, 2 and 3 inches per week of effluent over three equal areas of 0.225 acres. Site B contains a 150 ft rotary irrigator anchored on a center pivot. Six deflection heads 8 ft apart mounted downward and of decreasing opening diameter

toward the center deliver at the rate of 2 in of effluent per week to each of 4 subplots each encompassing 0.445 acres. Each subplot is equipped with banks of lysimeters which are used to sample interstitial groundwater from the depths of 0.5, 1, 2, 3, and 4 ft. A total of nine wells have been installed throughout both areas which are oriented according to groundwater flow so that groundwater monitoring can be provided throughout the experimental area. A high capacity retrieval well which is capable of pumping groundwater from a depth of about 60 ft at a rate of 300 gal/min also has been installed. Figure 4 shows the set-up of this system.

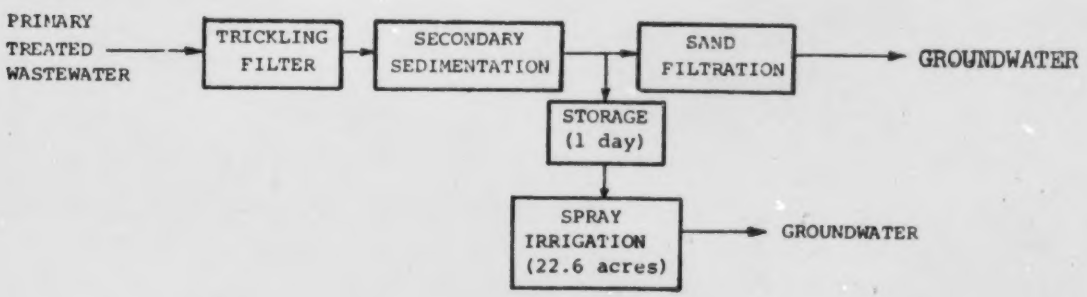

Figure 4. Presentation of the research land application facility for the Otis Air Force Base, Cape Cod, Massachusetts.

The monitoring program provides information on short and long term trends in terms of nitrogen, phosphorus, and trace metals removal after various degrees of treatment. All wells are constructed of PVC plastic which allows sampling for groundwater nutrients, metals and pesticides and many other organic substances without undue contamination. Monitoring within the sand beds is also provided by a series of suction lysimeters along with seven observation wells to determine the extent of wastewater renovation and the quality of the recharged water.

An extensive monitoring program at Otis Air Force Base provides data on long term trends in nitrogen, phosphorus, and trace metal removal after various degrees of treatment.

The removal of phosphorus from secondary effluent increases with the stage of treatment. The phosphorus concentration in the secondary effluent before lagooning ranged from about 8 to 10 ppm. The phosphate concentrations were higher during winter than in summer. Following chlorination and distribution over the irrigation field the phosphorus concentration was reduced to less than 0.5 ppm in the interstitial water recovered from 6 in. below the surface. At successively greater depths, no significant changes in phosphorus were observed down to the depth of groundwater sampling at 50 ft.

Total inorganic nitrogen concentrations in Otis secondary effluent before lagooning range from about 12.5 to 18.5 ppm and show a comparable reduction pattern to that of phosphorus following successive stages of treatment. During the winter-spring period, ammonia is the most abundant form of inorganic nitrogen in secondary effluent. During the summer and fall months, oxidized forms of nitrogen are more abundant than ammonia. In the interstitial soil water, the ammonia is almost completely adsorbed in the first foot of soil, but the oxidized forms of nitrogen penetrate at reduced concentrations to the groundwater. The data on inorganic nitrogen distribution suggest that soil nitrification is maintained at all seasons of the year.

The ability of sand filter beds to remove trace metals has been evaluated by sampling the soil at various depths. The heavy metals tend to accumulate within the upper few centimeters of sand. In terms of supply, the order of abundance for heavy metal additions to the sand filter bed was Cu>Zn>Cr = Pb>Cd. By comparing the integrated amounts of these metals distributed within the upper 52 cm with the heavy metal supply over the past 33 years it is possible to assign removal efficiencies for each of the five metals examined. Data indicate that

86% of the Cu, 49% of the Zn, 113% of Cd, 128% of the Pb and 59% of the Cr supplied are bound in the surface soil. Thus of the metals examined only Zn and possibly Cr would appear to have a reasonable chance of becoming entrained in the groundwater some 640 cm (21 ft) below the surface.

The crops grown on plots irrigated with more than 1 in/wk have provided 3.5 to 5 tons per acre per year. Moreover, these crops accumulate nitrogen, phosphorus, and cations calcium, magnesium, copper, chromium, and nickel within the plant tissues. There is excess phosphate-phosphorus in the effluent but like the heavy metals bound on the sand filter beds, this excess phosphorus becomes bound within the upper foot of soil. Significant phosphorus or heavy metal leaching into groundwater is not anticipated within the foreseeable future since more than 50 ft of soil above groundwater level remains available for adsorption. Excessive nitrate-nitrogen concentrations (50 ppm) in the wells monitoring the sand filter beds have been found, but the crops grown on the irrigation plots provide adequate control of this contaminant, and only trace amounts of nitrate (about 2 ppm) in the wells monitoring these irrigated plots have been found.

CASE STUDY COVER SHEET

SYSTEM Ft. Devens Rapid Infiltration (Name) 1942 (Date started)

LOCATION Ft. Devens, Mass. M. B. Satterwhite (Person involved)

FACILITY DESCRIPTION Municipal (waste classification) Rapid Infiltration (application system(s))

APPLICATION 1.1-1.4 ft/day (rate) apply 2 days with 14 days rest (schedule)

CROP(S) local weeds: annual "weedy" grasses, fall panicum, barnyard grass.

PRETREATMENT unchlorinated Imhoff tank effluent

VOLUME TREATED 1.3 mgd

WORKING YEAR 12 mo. CLIMATE ZONE D

SOIL sands or gravely sands

COST Annual O&M = $50,000

LAND AREA 16.6 acres

STORAGE CAPACITY none

COMMENT: Unchlorinated primary effluent from Imhoff tanks has been flooded onto sand filters since 1942 with virtually no monitoring system. Discharge goes to 22 treatment beds each about 0.8 acre in size constructed on an oval, steep sided mound of glacial sand and gravel, or kame. Filter beds are cleaned periodically (last time, 1968) by removing 1 ft of bottom, raking exposed surface, and replacing excavate with bank run sand and gravel. First monitoring done in 1974-1975. System now uses 14 observation wells.

REFERENCES: Satterwhite, M.B., G.L. Stewart, B.J. Condike, and E. Vlach. September 1976. Rapid infiltration of primary sewage effluent at Fort Devens, Massachusetts. CRREL Report 76-48, prepared for Directorate of Military Construction, Office, Chief of Engineers.

Satterwhite, M.B., B.J. Condike, and G.L. Stewart. Treatment of primary sewage effluent by rapid infiltration. CRREL Report 76-49. Prepared for Directorate of Military Construction, Office, Chief of Engineers.

Fort Devens Rapid Infiltration
Fort Devens, Massachusetts

Unchlorinated effluent from Imhoff tanks is flooded onto 17 acres of sand filtration beds with rapid infiltration capacities at Fort Devens.

The U.S. Military Installation of Fort Devens utilized the 17 acres of a kame (a beehive-shaped mound of glacial sand and gravel) for the construction of 22 rapid infiltration sand filter beds. Unchlorinated effluent from Imhoff tanks is flooded onto three beds for two days, then the beds are allowed to rest for 14 days. On a yearly basis, each bed receives effluent for a total of 52 days. Sludge from the Imhoff tanks is withdrawn each April and November and spread on sludge drying beds. Those beds are underdrained and the discharge sent to an adjacent wetland. Only two full-time employees are needed to carry out normal operation and maintenance of the facility. A schematic of this facility is shown in Figure 5.

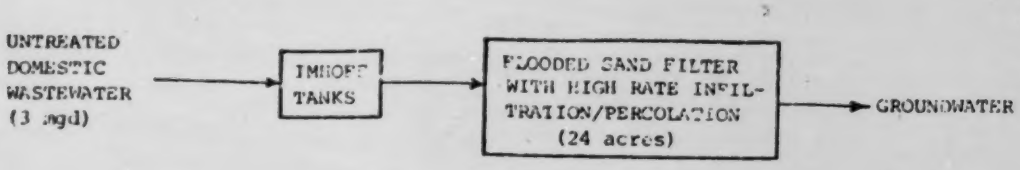

Figure 5. Illustration of the flow sequence followed at the Fort Devens, Massachusetts wastewater treatment facility.

The actual characteristics of this site were not fully defined until studies were begun in 1973. The soil profile is dominated by sand and gravel, with silts and clays accounting for only 10 to 15% of the volume in the upper profile and less than 1% below 1.6 ft. Permeabilities of 4×10^{-4} to 4×10^{-3} in./sec were recorded. Those rates are considered to be rapid to very rapid, and all horizons easily transmit the designed

daily flow of 3 MG/day. After the two days of flooding, effluent has normally accumulated on the surface of the beds to a depth of 0.5 to 1.6 ft. This standing water infiltrates the beds within the initial 2 to 3 days of the recovery period, restoring aerobic conditions to the surface of the beds. Winter conditions, while reducing infiltration rates somewhat, do not interfere with normal operations. The effluent is sufficiently warm, 46-54°F during the winter, to melt any accumulated ice and snow cover and to infiltrate and move through the sand beds.

Although winter temperatures reduce infiltration rates somewhat, the effluent is sufficiently warm to melt ice and snow cover and to move through the sand beds.

Chemical analyses of soil samples obtained from the upper 3.05 m of the treatment beds showed that levels of organic matter, electrical conductivity, nitrogen, copper, phosphates, calcium, magnesium, potassium, manganese, sodium, iron and zinc were substantially higher than those of background samples, whereas levels of sulfur, chloride, and cation exchange capacities were only slightly higher. Treatment bed soil samples had lower pH levels and boron concentrations than those found in background samples.

The quality of the primary effluent applied to the treatment beds and the groundwater in 14 observation wells was determined by sampling at biweekly intervals and analyzing the samples for pH, conductivity, alkalinity, hardness, five-day biochemical oxygen demand, chemical oxygen demand, total nitrogen, organic nitrogen, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, total phosphorus, orthophosphate, chloride, sulfate, and total coliform bacteria.

Groundwater quality in wells located 60 to 100 m from the application area showed that the primary effluent after flowing through the sand and gravel formation, had been substantially renovated.

Before treatment, effluent COD and BOD_5 levels in the groundwater were about 10 to 20 mg/l and 1.0 to 2.5 mg/l, respectively. Concentration of total nitrogen

in the primary effluent was 47 mg/1, which was divided equally among organic and ammonium forms.

Total nitrogen, primarily as nitrate nitrogen, in water samples from observation wells affected most was 10 to 20 mg/1. This was a reduction of about 60 to 80% in total nitrogen levels. Changes in the concentration and form of nitrogen showed that applied nitrogen was nitrified, with substantial nitrogen removal due mostly to denitrification.

Phosphorus levels in the primary effluent averaged 11 mg/1, 80% of which was orthophosphate. Total phosphorus levels in the groundwater were 1.0 to 2.0 mg/1, slightly above the 0.7 mg/1 background level. Orthophosphate was generally less than 0.4 mg/1 in wells located around the treatment area but was higher than the 0.1 mg/1 background level.

Chloride, sulfate, pH, and hardness levels varied little from observed effluent levels, although conductivity and alkalinity were substantially less. Analysis of groundwater samples of fecal coliform bacteria proved negative. Mean numbers of total coliform bacteria in the groundwater were less than 200/100 ml, although two wells showed mean counts of 400 to 600 organisms/100 ml of samples.

The cation exchange capacity (C.E.C.) of soils also has been characterized. Background C.E.C. values from unamended soils range from 2.0 to 8.0 meq/100g in surface horizons and about 0.5 meq/100g at depths greater than 1.6 ft. Cation exchange capacities of soil samples taken in treatment beds were relatively constant throughout the 9.8 ft sampling depth, ranging from 0.79-15.1 meq/100g.

The C.E.C. of the beds has increased over the six years since the beds were last renovated, presumably due to accumulations of organic matter.

An attempt was made in 1974 to increase denitrification by increasing the application rate. To achieve this, the application cycle was modified from inundating 3 beds for 2 days, followed by a 14-day recovery period, to inundating 9 beds for 7 days, followed by a 14-day recovery period. It was found that an increase in the inundation period continued to renovate the primary effluent to the same degree as before. The total nitrogen levels of the groundwater continued to be 20 mg/l. But when the treatment basins were inundated for 7 days, the percentage of total nitrogen removal was greater than when the basins were inundated for 2 days. By increasing the inundation period, total nitrogen additions were increased by 54% from about 32 to 50 lb/acre/day.

Although total nitrogen additions were larger during the 1974 study, a proportional increase in groundwater nitrogen levels was not observed, indicating a greater percentage of nitrogen removal.

However, after 6 months of increased inundation period, the infiltration capacity had been reduced so much that the basin surfaces were still wet at the beginning of the next cycle of inundation and recovery. This gradual decline in the basin infiltration capacity over several months was attributed to clogging of the surfaces of the basins by accumulating organic matter. It was found that an occasional extended recovery period of 60 consecutive days will rejuvenate the infiltration capacity of the treatment basins so that the 7-day application, 14-day recovery cycle can once again be used. The restoration of infiltration capacity during the extended recovery period is attributed to the aeration of the surface and the subsequent oxidation of accumulated organics.

Denitrification was increased at Fort Devens site by increasing the period of inundation. Increased inundation periods resulted in a greater accumulation of organic matter, thus reducing infiltration capacity of the site. This was alleviated by allowing an occasional extended recovery period of 60 days which rejuvenated the infiltration capacity.

Table 1. Chemical characteristics of primary effluent compared with water quality in wells 3, 4, 5, and 6 at Fort Devens.
Average values.

Parameter*	Effluent	Well 3	Well 4	Well 5	Well 6
pH (Standard Units)	6.2-8.0	6.3	6.9	7.0	7.1
Electrical conductivity (umhos/cm)	511	360	441	502	466
BOD_5	122	2.5	1.5	1.6	1.9
COD	192	19	29	28	34
Total Nitrogen	47	19.5	20.6	22.1	22.2
Organic-nitrogen	23	2.8	7.9	11	8.0
NH_4-N	21	1.3	6.4	7	8.4
NO_3-N	1.3	15.6	5.9	3.8	5.7
NO_2-N	0.02	0.3	0.4	0.3	0.1
Total PO_4-P	11	0.9	0.9	0.8	1.0
Ortho PO_4-P	9	0.2	0.3	0.1	0.2
Cl	150	257	157	159	155
SO_4	42	46	43	47	46

*mg/l unless otherwise noted.

Source: Satterwhite, Stewart, Condike, and Vlach, 1976.

Conclusions of study of Fort Devens system:

1. The rapid infiltration system has operated effectively throughout the year. Greater ponding of effluent was observed during winter than during warmer periods of the year.

2. The 2 days wet/14 days drying operation cycle has maintained infiltration and percolation capacities of the treatment beds after six years of field operation.

3. Levels of nitrogen, phosphorus, calcium, magnesium, potassium, iron, sodium, copper, zinc, chloride, and sulfur have increased in the soil surface horizon of the treatment beds.

4. Percolate from the treatment site has increased the levels of nitrogen, chloride, sulfate, conductivity, alkalinity, and hardness in the groundwater. Slight increases of BOD, COD, and total coliform bacteria levels have been observed.

5. Differences in the concentration of organic-nitrogen, NH_4-N, NO_3-N, and NO_2-N between the primary effluent and the groundwater illustrate that ammonification and nitrification were occurring in the treatment beds. A total nitrogen balance showed a 60% to 80% reduction in total nitrogen applied to the treatment beds.

6. Because of the limited capacities of the other plausible nitrogen removal mechanisms and the substantial quantities of nitrogen removed, the reduction in total nitrogen levels observed may be attributed to denitrification.

7. The groundwater quality in the strongly impacted wells indicates that the unchlorinated primary sewage effluent is being renovated to a quality comparable to that achieved by conventional tertiary wastewater treatment facilities.

CASE STUDY COVER SHEET

SYSTEM Fresno Wastewater Treatment (Name) — 1891 (1907) (Date started)

LOCATION Fresno County, Calif. — J. H. Jenks (Person Involved)

FACILITY DESCRIPTION Municipal and Vintage Wastewater (waste classification) — rapid infiltration (application system(s))

APPLICATION _____ (rate) (schedule)

CROP(S) primarily groundwater recharge; some use on cotton and pasture

PRETREATMENT primary clarifiers

VOLUME TREATED 34 mgd

WORKING YEAR 12 mo. CLIMATE ZONE A

SOIL "well drained", good ag. soil

COST _____

LAND AREA 1440 acres

STORAGE CAPACITY _____

COMMENT: This sanitary district in the San Joaquin Valley discharges all primary effluent to rapid infiltration beds. Groundwater mounding forces underdraining and drawdown pumping with discharge to adjacent pastures and cotton fields. Odors are a nuisance. Expansion facilities are being planned and will include secondary treatment. However, to control the water table, the practices of both recharge and irrigation will continue to be used.

REFERENCES: Jenks, J. H. and P. L. Adamson. 1972. Wastewater treatment disposal and reclamation project. Project Report, City of Fresno.

Fresno Wastewater Treatment
Fresno County, California

The Fresno County wastewater treatment facility originated in 1891 as a 40 acre "sewage farm" for raw sewage disposal. Expansion of facilities occurred seven times between 1907 and 1962. The 1924 expansion involved installing deep wells to draw down a prohibitively shallow water table (2 ft) caused by groundwater mounding. Water recovered from those wells was used to irrigate adjacent cotton fields and pastures. Some of that discharge occasionally ran into a nearby creek, but that was the only surface discharge. The 1960 expansion provided duplicate facilities ("Plant 1" and "Plant 2") with small oxidation ponds in addition to sludge thickeners, but discharge was still to the infiltration beds, with groundwater recharge the primary goal after waste treatment. A schematic presentation of this site is given in Figure 6.

Fresno County land application system has been greatly expanded since it began in 1891 as a "sewage farm".

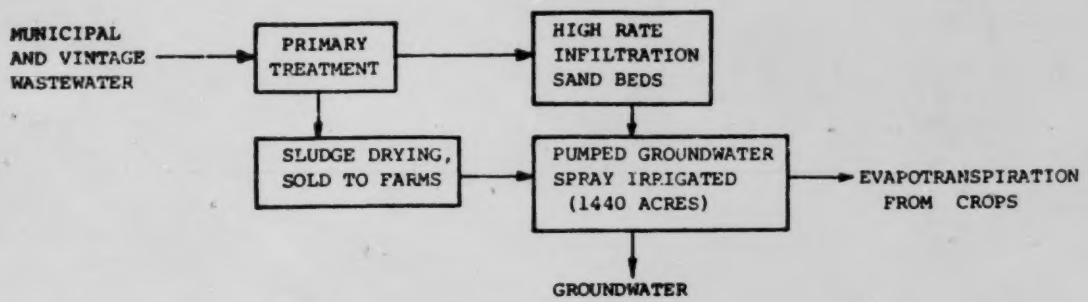

Figure 6. Schematic of the Fresno County, California land application system for wastewater treatment.

High wine production in recent years sent excessive amounts of vintage wastes to this facility, causing complete breakdown of sludge handling equipment. Wineries now must undertake preliminary sludge screening before discharging to sewers.

Wineries discharging to Fresno County land application system must undertake preliminary sludge screening to lessen the load on the county's sludge handling equipment.

The soils of the San Joaquin Valley are varied, mostly well drained alluvial deposits. Agriculture is the dominant industry. Virtually all water used comes from a highly adequate supply of fine quality groundwater. Reclaimed wastewater would be too expensive to sell as irrigation water even if transmission costs could be neglected. In 1968 groundwater around the facility was sampled from eight test holes and at each plant. Detailed chemical analyses of only two sampling sites are reported. Nitrate-nitrogen was measured at all sites, however, and ranged from "trace" to 213 mg/l. Toxic elements are not reported. Bicarbonates, carbonates, chlorides, sulfates, sodium, hardness, Fe, Si, Mn, Mg, and NH_4^+ are reported, reflecting the primary concern of that agricultural land toward "salt" content of waters.

Evapotranspiration from existing facilities is around 10 mgd in the summer. This high rate of water loss might be expected to lead to the concentrating of salt in the effluent. However, the quality of effluent, diluted some by native groundwater, is high enough to allow its use as irrigation water without causing salinity problems.

Odor problems have caused serious complaints. Those complaints, coupled with the growth in population and industry, mandate facility expansion. To solve those problems, officials are planning secondary treatment followed by continued land application. That will expand capabilities to 68 mgd. Presumably the proposed expansion will include monitoring capabilities and an established routine to assure compliance with federal and local regulations.

Sludges are dried and sold to local farmers as soil conditioner.

CASE STUDY COVER SHEET

SYSTEM Bakersfield, California (Name) 1912 (Date started)

LOCATION Bakersfield, California Larry Grimm, Metcalf & Eddy Engineers (Person involved)

FACILITY DESCRIPTION Municipal (waste classification) agricultural flood irrigation (ridge and furrow border strip) (application system)

APPLICATION at grower's discretion (rate) at grower's discretion (schedule)

CROP(S) alfalfa, barley, corn, cotton, pasture grass (unrestricted)

PRETREATMENT primary clarification and aerated lagoons

VOLUME TREATED 19 mgd

WORKING YEAR 12 months CLIMATE ZONE A

SOIL loam, clay loam, sandy loam

COST Of new system going into operation in 1978 $12.5 million

LAND AREA 5,700 acres of which 4,700 are under cultivation

STORAGE CAPACITY 1710MG or 90 days (under new system)

COMMENT: Bakersfield has two wastewater treatment plants, one of which will be closed down when the new system begins operation. Secondary effluent will be sent to a ditch or force mains from which irrigation water is withdrawn. All land is leased to one grower who must use all the water all the year but can establish his own management practices. Forage, fiber and seed crops are grown. The new system is currently under construction and will be operational by Fall, 1979.

REFERENCES: Crites, R.W. 1974. Irrigation with wastewater at Bakersfield, California. In: Wastewater Use in the Production of Food and Fiber, EPA-660/2-74-041. pp. 229-239.

Crites, R.W. 1973 (?) Wastewater irrigation: This city can show you how. (Further specific bibliographic information not available).

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CASE STUDY COVER SHEET (continued)

Metcalf and Eddy, Inc. 1973. Preliminary investigation of wastewater treatment and disposal for southeast Bakersfield. Prepared for the City of Bakersfield and Mount Vernon County Sanitation District.

Process Design Manual for Land Treatment of Municipal Wastewater, U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Department of Agriculture. October 1977. EPA 625/1-77-008. pp. 7-18 to 7-26.

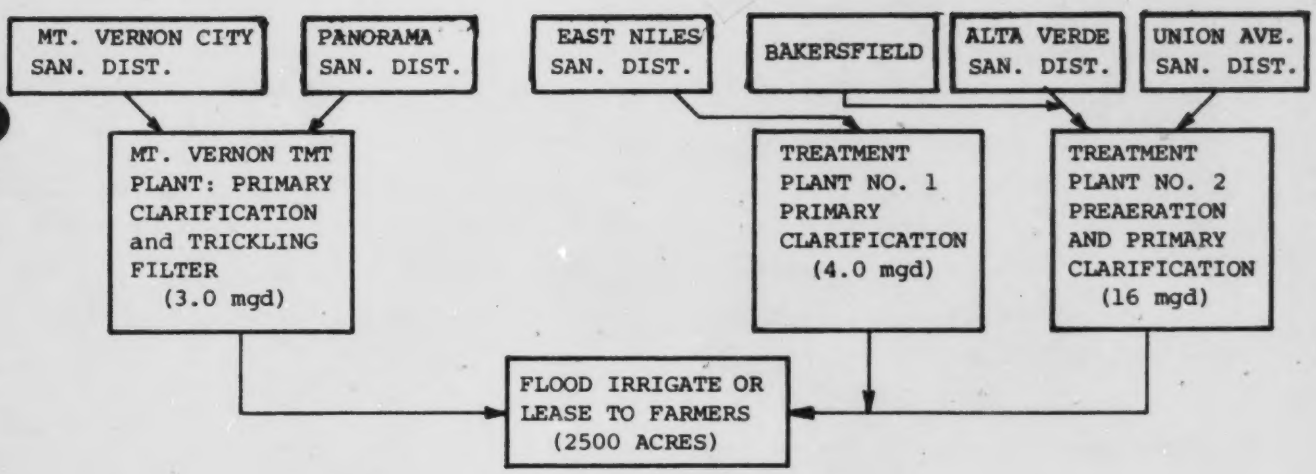
MT. VERNON CITY SAN. DIST.
PANORAMA SAN. DIST.
EAST NILES SAN. DIST.
BAKERSFIELD
ALTA VERDE SAN. DIST.
UNION AVE. SAN. DIST.
MT. VERNON TMT PLANT: PRIMARY CLARIFICATION and TRICKLING FILTER (3.0 mgd)
TREATMENT PLANT NO. 1 PRIMARY CLARIFICATION (4.0 mgd)
TREATMENT PLANT NO. 2 PREAERATION AND PRIMARY CLARIFICATION (16 mgd)
FLOOD IRRIGATE OR LEASE TO FARMERS (2500 ACRES)

Figure 7. Simplified schematic presentation of the wastewater treatment system for Bakersfield, California.

Bakersfield, California

Land application of wastewater has been practiced for more than 60 years at Bakersfield in the San Joaquin Valley of Central California. Untreated wastewater was first used to irrigate crops in 1912. Since 1939, city-owned lands planted with forage, fiber, and seed crops have been irrigated with treated municipal wastewater. Primary treatment plants constructed in 1939 and 1952 service about half of the metropolitan area which has a total population of 200,000. These plants supply the wastewater for the current 2,400 acre farm, soon to be expanded to 4,700 acres. The farm is leased to a grower who irrigates year-round using surface distribution methods. Year-round irrigation is possible because of warm arid climate. Soils have been described as "poor quality" worth $100/acre before application and have been improved with wastes application to $1,000/acre.

The land application in Bakersfield supplies irrigation water for a 2,700 acre farm, soon to be expanded to 4,700 acres.

Because certain deficiencies have developed in the operation, the existing facilities are being expanded and upgraded. The existing system consists of a network of ditches and equalizing reservoirs supplying the fields with wastewater for border strip and ridge and furrow methods of irrigation. Although the topography is very flat, the drainage is from north to south with sump pumps along the southern end to return tailwater to storage ponds. Soils are generally alkaline and poorly drained with dense clay lenses at depths ranging from 10 to 15 ft below the surface. This clay barrier produces perched water in areas where it is continuous and reduced percolation in areas where it is not.

Two permanent groundwater aquifers exist at approximate depths of 100 to 200 ft and at 300 ft. They are separated by a clay barrier, and the confined lower aquifer is used for water supply. The deep wells on the farm produce water to supplement irrigation needs. The quality

of this water, however, is inadequate for potable uses as a result of naturally occurring high total dissolved solids and nitrates.

Liquid and nitrogen loading rates, and nitrogen requirements for the principal crops grown on the farm are shown in Table 2. The nitrogen applied meets the nitrogen uptake of all crops. For cotton, the nitrogen loading is more than twice that which can be utilized. Yields for all other crops are about equal to, and in some cases higher than, the county-wide averages. Crop yields resulting from irrigation with primary effluent and the economic return are shown in Table 3.

Table 2. Crops, Irrigation Land, and Nutrient Uptake at Bakersfield, California (Crites, 1973).

Crop	Liquid Load Rate	BOD Load Rate	N Load	N Uptake
	ft/yr	lb/acre/yr	lb/acre/yr	lb/acre/yr
Barley	1.8	730	139	75
Corn	3.3	1300	252	150
Cotton	3.7	1500	277	100
Pasture Grass	4.9	1985	371	150-250
Alfalfa	4.9	1985	371	360-480

Conversion factors: lbs/acre = 1.12 kg/ha;
ft x 30.5 = cm

Management of water has been a problem due to lack of storage and increasing flows. This will be resolved under the new system with its 90-day storage facilities. Ponding of excess water has occurred on some areas of the pastureland in winter. Although flies and mosquitoes are attracted to the stagnant water, no diseases have been traced to effluent use. The equalizing reservoirs and the storage pond for tailwater are periodically sprayed to control mosquito propagation. No disinfection of the effluent is required and none is provided at the two treatment plants. Normally, corn and barley are green chopped for cattle fodder and not harvested for grain. Dairy cows are not allowed to graze pastures irrigated with nondisinfected effluent so they are fed with green chop and hay. Beef cattle are allowed to both graze pastures and be fed on the green chop and hay.

The problem of managing large volumes of wastewater and balancing flow with irrigation needs will be resolved by the installation of 90-day storage facilities at Bakersfield.

Although primary effluent is suitable according to the California Department of Health, the Central Valley Regional Water Quality Control Board has set limits of 40 mg/l on BOD and suspended solids prior to forage crop irrigation. Their rationale is that such an effluent can be stored without causing a nuisance and will reduce the potential for odors in system management.

Under the proposed system, the existing preapplication facilities will be upgraded and a concrete pipe distribution system for continued surface irrigation of crops will be built. One of the treatment plants will be shut down and its flow redirected to the remaining plant where new primary clarifiers and aerated lagoons will be constructed. There will be no chlorination because surface application to forage, fiber and seed crops does not require disinfection.

The main objective of the new Bakersfield system will be to produce crops rather than to treat wastewater; double cropping of corn and barley will be used.

The new 4700-acre system will have as its principal objective to produce crops rather than to treat wastewater. Thus, double cropping with corn and barley is proposed. This combination requires less water than is presently applied.

Flexibility of operation will be provided by storage reservoirs, which will hold flows during periods of low irrigation demand. Automatically operated tailwater return stations will control runoff from irrigated fields. Outlets from the distribution laterals will consist of orchard-type valves which can be adapted to gated surface pipe, open ditches with siphon pipe, or direct flooding of border strips. Telemetered alarms will continuously scan the operation of the system to alert the operator of malfunctions at any of the pumping stations.

Table 3 shows the city revenues from the lease of the existing farm land, which amount to 20% of the operating and maintenance costs.

Table 3. Existing crop yields and economic return, Bakersfield land treatment system

Crop	Yield lb/acre	Typical Price $/lb[a]	Economic Return $/acre
Alfalfa	16,000	0.025	400
Barley	3,000-5,000	0.045	135-225
Corn	36,000-60,000	0.0075	270-450
Cotton	600-800	0.35	210-280

[a] Based on 1973 prices.

1 lb/acre = 1.12 kg/ha
1 $/lb = $2.2/kg
1 $/acre = $2.47/ha

Source: Metcalf and Eddy, 1977.

CASE STUDY COVER SHEET

SYSTEM Deer Creek Lake (Name) — 1973 (Date started)

LOCATION 30 mi. S.W. Columbus, Ohio — D. J. Lambert/Corps of Eng. (Person involved)

FACILITY DESCRIPTION domestic (waste classification) — spray irrigation (application system(s))

APPLICATION 0.1 in. per hour (rate) — 10 hr day. — Maximum load 1 in. per week over entire site (schedule)

CROP(S) alfalfa, reed canary grass, wheat/soybeans, tree seedlings

PRETREATMENT lagoon

VOLUME TREATED .046 mgd

WORKING YEAR 12 months CLIMATE ZONE D

SOIL "poorly drained", moderately slow to slow permeability

COST

LAND AREA 12 acres

STORAGE CAPACITY 9.0×10^6 gal

COMMENT: This site serves a 232-unit camping area having peak visitation of 16,500/month and annual visitation of 1.6 million persons. It was designed and constructed by the Army Corps of Engineers and is now operated by the Ohio Department of Natural Resources. It provides two lagoons and a spray irrigation field. The field is underdrained. Underdrain and overland flow effluent is returned to lagoons or, if high enough quality, to nearby Deer Creek Lake. A 1000-2000 ft buffer of vegetation separates spray field from camp site. The system has performed adequately to meet all point discharge requirements under PL 92-500. The crop management program has shown that grasses, alfalfa, and soybeans can be grown when the application rate for these low permeable soils does not exceed one inch per week. The system removes nitrogen, phosphorus, and BOD sufficiently to meet drinking water standards in the percolating water. The monitoring system has performed satisfactorily and a detailed data base for product water quality has been established.

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CASE STUDY COVER SHEET (continued)

REFERENCES: Lambert, D. J. and W. R. Dawson. 1975. The living filter comes to Deer Creek. Water Spectrum. 6(1):1-8.

Lambert, D. J. and H. L. McKim. 1977. Deer Creek Lake - on-land wastewater treatment system, pp. 79-93 In R. C. Loehr, ed. Food, fertilizer and agricultural residues. Proc. 9th Cornell Univ. Agricultural Waste Management Conference.

Deer Creek Lake
Recreational Area, Ohio

At Deer Creek Lake campsite, partially treated wastewater is pumped from a holding basin to a 12-acre site where it is sprayed onto slowly permeable soil planted in alfalfa, reed canarygrass, wheat, soybeans, and tree seedlings.

The Deer Creek Lake system treats the wastewater from one of the camping sites at the Deer Creek Lake Reservoir. The site accommodates trailers and tents. Sanitary facilities include a central sewage dump station with multiple slop drains for trailers, six comfort stations, and four wash houses. The wastewater sources feed into two lift stations located at the camping site. Wastewater then passes through underground drains and is pumped to the stabilization lagoon.

The complete treatment system is composed of a stabilization lagoon, chlorine contact chamber, holding basin, pump intake, distribution piping and four three-acre spray fields. Any runoff outside the spray area is diverted by a berm located around the entire spray area. Runoff from the spray area flows through a series of ditches and is collected at the lower end of the 12-acre spray field. An underdrainage system which collects the water that percolates through the soil is installed at a depth of three feet. The soils comprising the majority of the land in the treatment area have neutral to alkaline pH and have moderately slow to slow permeability rates as classified by the Soil Conservation Service. The clay content below 30 inches always exceeds 36%.

The stabilization lagoon and holding basin were part of the original two-lagoon sewage treatment system installed at Deer Creek Lake in 1973 to handle a flow of 46,000 gpd, which was the anticipated maximum weekend flow to be pumped from the 232 campsites at the Deer Creek Lake camping area. The primary lagoon was designed to hold 73 days of maximum flow at normal depth and could be raised up to two feet to store an additional 60 days. A secondary lagoon, originally intended to polish the effluent from the stabilization lagoon, was converted to a holding basin capable of storing 62 days at maximum flow. The chlorination point is located between the

stabilization lagoon and the holding basin.

The partially treated wastewater is pumped from the holding basin at 560 gallons per minute to the 12-acre spray field for an average application rate of 0.1 inch per hour. The pumping is limited to 10-hour periods to ensure that more than one inch of effluent is not applied per week. The natural slope of the spray field, averaging 1%, was left undisturbed in order to maintain the existing soil profile except for the trenching required to install the underdrain system.

Flexibility is designed into the spray system. Any two of the three units in the pump house can accommodate the design flow of 560 gpm, leaving the third as a standby pump. The entire flow of 280 gpm from one pump can be sprayed into any of the four equally sized three-acre parallel sections into which the spray field is divided. Furthermore, each pump is equipped with individual intake screens so that each intake can be back-flushed by the flow from the other pumps if the screens become clogged. All header pipes and supply lines are placed underground, not only to make the area more aesthetically acceptable, but also to decrease the time involved in the cutting, trimming, and harvesting of the vegetative cover.

Underdrains allow the application of wastewater in early spring. These drains were placed parallel to the spray header lines on 30-foot centers. Each drain consists of a six-inch corrugated, flexible plastic pipe with a filter sleeve. All the percolating water can be analyzed and discharged to the reservoir or primary holding lagoon based on the water quality analyses.

The monitoring system ensures that water entering Deer Creek Lake meets water quality goals. It also provides a data base that will enable more accurate assessment of management and cropping practices required for design and construction of cost effective land treatment systems.

Wastewater is monitored at eight critical locations in the land treatment system. Raw sewage is monitored by a device activated by the start-up of sewage flow which collects a composite sample for water quality analysis. An automatically activated timing device provides for representative samples of the holding lagoon effluent. Composite samples are collected at the point when the pump that transports wastewater to the spray irrigation field is activated. Accurate flow rates and water quality analyses are needed at this point to ensure that water and nutrient mass balances for the spray area can be calculated. Overland runoff and subsurface drainage are measured by automatic flow recording devices. Since the system was designed and is operated to ensure that the wastewater applied will infiltrate into the soil, any runoff from the site is attributed to rainfall. When runoff occurs, grab samples are collected at these points and analyzed for water quality. The quality of the renovated wastewater in subsurface drains indicates whether the water meets advanced treatment requirements allowing discharge into Deer Creek Lake, or must be recycled to the stabilization lagoon for further treatment. Other monitoring points consist of shallow wells where the level of phreatic water surface is visible. These wells are sampled to determine the effect of spray irrigation on groundwater quality. Table 4 indicates water quality at five of these monitoring locations.

If the quality of renovated wastewater in subsurface drains does not meet requirements for discharge into Deer Creek Lake, it is recycled to the stabilization lagoon for further treatment.

Table 4. Characteristics of Wastewater Collected from Various Points at Deer Creek Lake Land Treatment System. (Adapted from Lambert and McKim, 1977).

Constituents	Raw Sewage (ppm)	*Point 3 (ppm)	Point 4 (ppm)	Point 5 (ppm)	Point 6.1 (ppm)
Chlorides	269	49 - 76	6 - 25	4 - 73	6.0 - 19.6
Phosphate	6	0.11-0.25	0.00 - 2.34	0.0-0.10	0.02-1.96
Total nitrogen	50.6	1.9	0.2-2.5	-	0.4 - 2.2
NH_4^+-N	33.8	0.0 - 0.3	0.0-2.7	0.0 - 0.6	0.3 - 0.5
NO_3^--N	1.5	0.0 - 0.4	0.0-0.4	0.0 - 2.0	0.2
Total solids	1250	320 - 430	193-505	93-1000	300-1462
Volatile solids	330	86 - 229	22-249	23-180	145-219
pH	8.3	8.5-8.7	7.6-8.2	7.1-8.2	7.5-7.6
BOD	134	2.6-3.4	2.4-10	0.3-7.9	1.8-7.2
Fecal coliforms MPN/100 ml	$1.3X10^7$	0-240	30-$5.5X10^4$	0-600	0

*Point 3: Wastewater used as spray irrigation (pumping site)

Point 4: Surface runoff

Point 5: Drainage water

Point 6.1: Water collected from one of the shallow wells

CASE STUDY COVER SHEET

SYSTEM Winter Spray Irrigation (Bromley) (Name) — 1972 (Date started)

LOCATION Big Bromley Ski Area — Peter Andrews, Dufresne-Henry Eng. Corp, Springfield, Vt. (Person involved)

FACILITY DESCRIPTION 1.7 in/week for 24-36 hr continual (rate) — winter ski season (schedule)

CROP(S) none

PRETREATMENT aeration/lagoon

VOLUME TREATED 20,000 - 60,000 gal/day

WORKING YEAR 12 weeks CLIMATE ZONE E

SOIL mountain forest/clearing

COST $25,000 grant

LAND AREA 2.47 acres

STORAGE CAPACITY

COMMENT: A research and demonstration project in which chlorinated secondary effluent is sprayed onto forest and clearcut land during Vermont winters. Many different types of nozzles have undergone experimentation including fixed and rotating. Sprinklers remain ice-free day and night. Icing on trees and branches and formation of ice "chalices" around sprays is a problem. Chalices are donut-shaped ice structures which form around the nozzles. On one occasion about 90% of the system was blocked by such icing. Chalicing may be controlled by downward spraying. Renovation of water is acceptable. Dufresne-Henry calls the system "ice piling". Effluent is sprayed sometimes at -20°F. The spraying creates ice piles which melt in the spring, creating a large runoff. Movement of effluent through the soil is more horizontal than vertical. Large amounts of surface runoff are not a problem because there are no wells within a 20-mile radius of the site.

(continued on next page)

CASE STUDY COVER SHEET (continued)

REFERENCES: Dufresne-Henry Egn. Corp. 1972, Winter spray irrigation demonstration Bromley Ski Area, Vermont. A report on water quality effects by the Vermont Dept. of Water Resources, Project No. D-H #2140 (August 17, 1972).

Winter Spray Irrigation
Big Bromley Ski Area
Manchester, Vermont

This full scale demonstration/research project was undertaken to determine the feasibility of wastewater renovation by winter land application. The site selected represents a major ski area providing from 20,000 gpd to 60,000 gpd with an established secondary treatment system (lagoon). The land for application was a nearby abandoned ski slope. The area selected was about 50% forested and 50% open field. Slopes ranged from 10% to 25% (average 17%) and soils were shallow, no more than 3 feet.

Wastewater at the rate of 20,000 to 60,000 gpd receives secondary treatment and is sprayed on an abondoned ski slope throughout the ski season at Big Bromley Ski area.

Monitoring was done using three plywood-lined pits, downslope from the spray zone. Perforated pipes were pounded through the walls of the pits into the soil to act as sample collectors. In addition, surface runoff from below the spray zone and an adjacent brook were sampled on weekdays. Parameters examined included pH, BOD, COD, TDS, PO_4^{-3}, NO_3^-, Cl^-, and SO_4^{-2}. The pH went from an average of about 6.9 to 5.6 in the field and 6.2 in the woods. The BOD went from an average of 4.7 mg/l to 2.0 mg/l in the field and 1.7 mg/l in the woods. The PO_4^{-3} went from an average of 17.0 mg/l to 0.7 mg/l in the woods. No NO_3^- removal occurred. Concentrations of all parameters increased sharply at spring runoff. However, there are no wells within a 20-mile radius.

A special feature of winter spraying is that effluent storage occurs in the forms of large ice mounds. However, renovation occurs only after the effluent passes into the soil. Renovation, then, depends on the slow but steady melting which occurs beneath the insulating layers of ice. Larger volumes of effluent are released to soils during periods of winter melt. If soil capacity is not exceeded during such periods, application by spraying may be increased temporarily to encourage ice melt and allow more effluent to be processed before spring thaw.

Effluent stored in large ice mounds throughout the winter is renovated only after it passes into the soil. Although steady melting occurs in winter, the largest volumes are released during spring thaw when concentrations of BOD, COD, PO_4^{-3}, NO_3^-, Cl^-, and SO_4^{-2}, sharply increase.

At the time of spring thaw, soils experience excessive hydraulic loadings due to snow melt and rains. Effluent stored in ice mounds will be diluted and lost to surface run-off, but the larger and thicker the ice mounds, the more slowly they will melt. Thus, winter spraying must rely on spring dilution instead of soil renovation to process the remaining effluent.

Non-chlorinated effluent was sprayed on occasions to test the spread of air-borne pathogens from the spray area. The conclusion was that pathogens were present but significantly reduced after 150 to 200 ft downwind from the last nozzle. None were detected beyond 300 feet.

A number of spray nozzles were used and some icing and pipe-freezing problems were reported, but it was felt that there was nothing that could not be handled with experience. Aesthetic considerations were not forgotten. Spraying from fixed nozzles was silent and the spray so finely atomized that visitors were genuinely disappointed with the apparent lack of action. Risers in the wooded portion of the site were well camouflaged.

CASE STUDY COVER SHEET

SYSTEM Campbell Soup Company (Name) — 1964 (Date started)

LOCATION Paris, Texas — Charles H. Neeley (Person involved)

FACILITY DESCRIPTION Cannery wastes (waste classification) — Overland flow (application system(s))

APPLICATION 2 to 3 in/wk (rate) — Three 6-8 hr days per week, 16 to 18 hours off (schedule)

CROP(S) primarily reed canary grass, red top, perennial rye grass, bermuda grass, tall fescue, native vegetation

PRETREATMENT screen and degrease

VOLUME TREATED 6 mgd

WORKING YEAR 12 months CLIMATE ZONE C

SOIL Sandy loam, clay, clay loam

COST 28c/1000 gal.

LAND AREA 900 acres

STORAGE CAPACITY none

COMMENT: A sprayed effluent is allowed to flow down 150-200 ft slopes ranging from 2% to 6% over highly eroded, nearly impervious soils. Grasses are harvested two or three times a year as cash hay crops. Reed canary grass was found to be an exceptionally good hay when harvested early. Up to 90% N and 61% P removal is achieved. Effluent BOD is always 10 ppm, representing a 99% reduction in BOD.

REFERENCES: Gilde, L. C., A. S. Kester, J. P. Law, C. H. Neeley, and D. M. Parmlee. 1971. A spray irrigation system for treatment of cannery wastes. J. Water Poll. Control Fed. 43(10):2011-2025.

C. W. Thornthwaite Associates. 1969. An evaluation of cannery waste disposal by overland flow spray irrigation. Publications in Climatology Vol. 22, No. 2. 73 p. Laboratory of Climatology, Elmer, N.J.

Campbell Soup Company
Paris, Texas

In the early 1950's, the Campbell Soup Company gained experience in overland flow operation from handling its 0.75 mgd tomato waste in Napoleon, Ohio. That experience with seasonal flow encouraged them to develop a plant in Chestertown, Maryland (1959) which processed poultry wastes throughout the year. Based on these two studies, Campbell began an overland flow system in Paris, Texas, in 1960, going into full operation in 1964.

When the company acquired the site in 1960, most of the topsoil had been stripped away, much of the area was covered with brush and small trees, and the old erosion gullies had cut deeply into the red clay subsoil. The trees were cut down and destroyed; the erosion features were eliminated with heavy earthmoving equipment. The slopes were then smoothed with a land plane and planted to water tolerant grasses. When the grass became established, terraces were spaced at 200 and 300 foot intervals downslope. Underground force mains were installed with automatic valve take offs located 135 feet or more upslope from each terrace. From these, surface irrigation lines extended across the slope. For more than a year, while the factory was being built, the grass on the slopes was fertilized and irrigated with fresh water to establish a good growth of sod.

The overland flow site at the Paris Campbell Soup plant was prepared by removing all trees, eliminating erosion features with earthmoving equipment, smoothing slopes with a land plane and planting water tolerant grasses.

The Paris plant prepares a complete line of heat-processed soups as well as beans and spaghetti products. Effluent is screened and degreased, then sent to a storage tank for distribution. Lateral sprinkler lines are designed to operate eight hours on and 16 hours off, allowing for a rest period between wastewater application. Water containing suspended and dissolved organic impurities is sprayed along the top of the slope by conventional irrigation sprinklers. As it percolates through the dense sod to the soil surface, it leaves behind most of the suspended solids. From here the

water trickles downslope in a thin sheet and the dissolved impurities are subjected to biological degradation. The purified water is collected in the terrace at the foot of the slope whence it flows to the receiving stream via prepared waterways. A schematic presentation of this treatment system appears in Figure 8. Table 5 shows removal efficiencies of the Paris system.

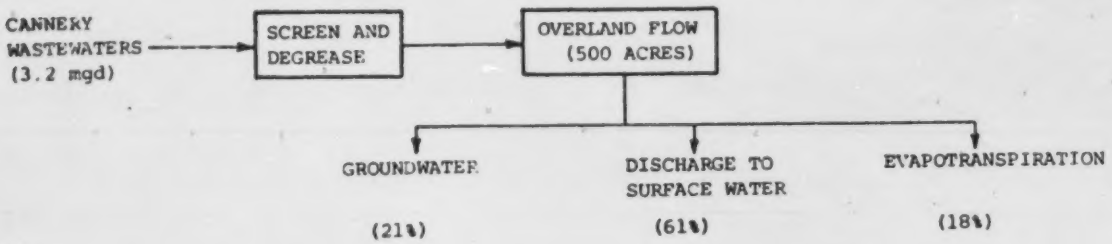

Figure 8. Presentation of the land application system used for cannery wastewaters by the Campbell Soup Company, Paris, Texas.

Table 5. Treatment Efficiency of Campbell Soup System, Paris, Texas. (Source: Gilde, Date Unknown).

Parameter	Mean Conc. mg/l		% Removal	
	Inf.	Eff.	Conc.	Mass
TSS	263	16	93.5	98.2
BOD	616	9	98.5	99.1
P	7.6	4.3	42.5	61.5
N	17.4	2.8	83.9	91.5

The biological and agricultural response to waste loading has been studied by North Texas State University and an extensive study on the climatology, agriculture, biology, hydrology and chemistry of the site was done by C. W. Thornthwaite Associates of Elmer, New Jersey.

What is the fate of the applied wastewater in the Paris system? Results indicate that 20% percolates down through the soil, 10 to 30% is lost by evaporation and transpiration, and the remaining 60% returns to the surface stream as runoff.

The system removes nutrients efficiently. 99% of the applied BOD and up to 90% of the applied nitrogen and phosphorus can be removed under favorable conditions. Early observations revealed that the removal of phosphorus was disappointingly low -- about 45%. Later a change in the operating procedure to provide a longer rest period between applications, with no change in the total volume, increased phosphorus removal to nearly 90% without affecting the BOD or nitrogen removals.

Investigations showed that the Paris system operated as efficiently in winter as in other seasons. This is due to a tenfold increase in the population of microorganisms in winter. It has long been recognized that an overland flow system would continue to purify water when temperatures were near freezing, but since it is also known that respiration of microorganisms slows down as temperature decreases, it was believed that the impurities were being adsorbed upon the surface of the vegetation and held there until the weather warmed up again. The studies showing increase of microorganism numbers during winter indicate a constant level of activity of the microbial mass, which should account for the continued high removal efficiency.

The Paris overland flow system operates as well in winter as in other seasons; research shows that the population of microorganisms increases tenfold in winter thus compensating for any decrease in respiration of microorganisms under cold temperatures.

Chemical analyses of the soil indicate that while the concentration of sodium salts is increasing, it has not reached a level injurious to plants and is not expected to do so in the future. Similarly, nitrates percolating into the groundwater reserve are not expected to build up to the point of concern.

Young grasses, particularly reed canary grass, grown on irrigated lands have nearly twice the phosphorus and protein of non-irrigated grasses. This makes irrigated grasses nearly as nutritional as alfalfa. Furthermore, if cut while still tender, irrigated grasses are readily eaten by cattle. Thus two or even three harvests of hay are taken each year as a normal, cash-producing asset of the Paris system.

CASE STUDY COVER SHEET

SYSTEM Muskegon County (Name) — 1974 (Date started)

LOCATION Muskegon, Michigan — Mr. Ralph Precious, Adm. (Person involved)

FACILITY DESCRIPTION municipal/industrial (waste classification) — spray irrigation (application system(s))

APPLICATION 2.1 in./week (rate) — 7 days per month (schedule)

CROP(S) Winter wheat, corn, rye, oats, legumes, grass cash crops

PRETREATMENT lagoon

VOLUME TREATED 43.4 mgd

WORKING YEAR 212 days CLIMATE ZONE E

SOIL Sand (some poorly drained)

COST \$44 x 10^6 (tot); \$40/10^6 gal 1st year

LAND AREA 10,000 acres

STORAGE CAPACITY 30,000 acre ft.

COMMENT: Widely discussed system for treating wastes of 14 municipalities and 200 industries of a west central Michigan region. Influent goes into three 8-acre aeration lagoons, two 850-acre storage lagoons, and an 8-acre solids settling pond. Effluent is spray irrigated by center pivot rigs onto underdrained agricultural land. System is monitored by some 302 wells, stores effluent over winter, chlorinates before spraying, has minor odor problems at influent.

REFERENCES: Forestell, W. L. 1973, Sewage farming takes giant step forward. The American City, October: 73-74.

Chaiken, E.I., S. Poloncsik, C. D. Wilson. 1973, Muskegon sprays sewage effluents on land, Civil Engineering. ASCE. May. (reprint by U.S. EPA, Region V, Wacker Dr., Chicago, Illinois 60606).

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Bauer, W. J. 1975. Review of design parameters for Muskegon County Wastewater Management System No. 1 after two years of operation. Presented at Conference on the Muskegon County, Michigan Wastewater Management System. Sept. 17-18, 1975. Muskegon County Community College.

Demirjian, Y. A. 1975. Land treatment of municipal wastewater effluents. Prepared for the U.S. EPA Technology Transfer Program (Oct.)

EPA. 1976. Wastewater: is Muskegon County's solution your solution? EPA-905/2-76-00. Region V, Chicago, Illinois.

Muskegon County
Muskegon, Michigan

The 10,000 acre Muskegon County Wastewater System, which has won engineering awards, necessitated the moving of many landowners, farmers, and businesses, and was accomplished in the face of strong citizen opposition.

This $44 million project has won engineering awards and is often considered to be a significant demonstration of a fine land application system. The county received 45% of its funding from Federal sources. Wastes are collected from 14 municipalities and 200 industries, transported through a 13-mile interceptor system to an 11-mile force main and then to three 8-acre aeration lagoons. The lagoons may operate either in parallel or series. After a 3 day retention time, discharge is to one of two 850-acre storage lakes where settling occurs. Effluent from the storage lakes (capacity equal to 6 months flow) is chlorinated and sprayed onto 7500 acres of agricultural land through 55 center pivot rigs.

The county-wide system has two separate wastewater treatment areas, a 10,500 acre site near Muskegon and a 600-acre site near Whitehall. The crops vary, but corn is the most extensively grown. The land is underdrained with tiles buried 7 to 11 ft. Percolate is discharged to Lake Michigan via Mosquito Creek or Black Creek. It is hoped that one by-product of this system will be to reduce the pollution in Mona and White Lakes and allow them to recover from their eutrophic condition.

This project moved 154 landowners, 30 tenants, 2 farm owners, 4 businesses, and 2 non-profit organizations from the acquired land. Moving costs were unexpectedly high. Land clearing was expensive because air pollution regulations prevented burning of felled trees. A strong citizen suit was also fought by filing a countersuit. Citizen groups feared gross environmental pollution from the proposed land treatment facility. Of particular interest is the fact that this project originated as an effort to attract industry to an economically depressed

region with unemployment at 11 to 13%, twice the national average. Adequate wastewater treatment was seen as a key issue, and that led to the present system.

The soil at the site is very sandy with a 10 in/hr infiltration rate, which is considerably decreased upon plowing, and capable of holding 0.02 to 0.05 inches of water per inch of soil. The soil is underlain by impervious clay slanting upward and emerging at the south end of the site. The clay layer, water table, and low capacity for water require underdraining. Discharge is to easily maintained open channels before going to nearby creeks. Before construction, the groundwater table was very close to the soil surface in many of the fields. Tile drainage or drainage wells were installed and the water table lowered. The drainage network now collects the sprayed renovated wastewater after it has percolated through the crop soil filter and discharges it into the receiving stream. The drainage network, along with interception ditches around the storage lagoon, is designed to protect the quality of the groundwater. Another interesting aspect of the site-drainage system is the bypassing of all drainage from lands upstream, and construction of berms to prevent storm water runoff from the site.

A shallow groundwater table was lowered at the Muskegon site by installing tile drains or drainage wells.

Soil pH ranges from 4.5 to 6.0. Soil C.E.C. and toxic element load are not specified in the literature cited. The site has a 250 ft buffer zone around its entire periphery which is used as a sanitary landfill. The flow design for this facility is given in Figure 9.

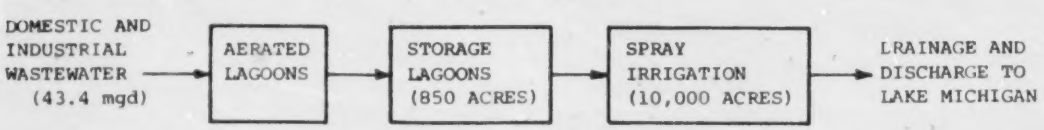
DOMESTIC AND INDUSTRIAL WASTEWATER (43.4 mgd)
AERATED LAGOONS
STORAGE LAGOONS (850 ACRES)
SPRAY IRRIGATION (10,000 ACRES)
LRAINAGE AND DISCHARGE TO LAKE MICHIGAN

Figure 9. Illustration of the land application system for the treatment of wastewaters used by Muskegon County, Michigan.

After reaching the treatment site, wastewater can be aerated in each of the three 8-acre, 42 MG capacity aeration cells. There are six 50-horsepower mixers and 12 60-horsepower aerators in each cell. Research and operating experience justified reducing the amount of aeration needed. This cut down drastically on electrical energy used. The aeration mode most often used at this time is treatment with 8 aerators in Cell 1 followed by treatment with 4 aerators in Cell 2. With the current 27 mgd flow, the average retention time is about 1.5 days in each cell.

After aeration in winter, the water flows into the storage lagoons. During the summer, the aerated water may either be sent into storage or retained briefly in an 8-acre solids settling cell before application on land through the irrigation system. There are two storage lagoons, each 850 acres in size, with a combined storage capacity of 5 billion gallons.

Before water is irrigated onto the land, it enters a discharge cell. Prior to entering irrigation ditches that supply water to pumping stations, the water is chlorinated as necessary to meet health standards.

The pretreated wastewater is distributed to center pivot irrigation rigs via buried asbestos cement pipes. The operating pressure is from 30 to 70 psi depending upon the location in the system. The rigs were especially designed for spraying wastewater with downward pointing low pressure nozzles. There are 54 center pivot irrigation rigs located in circular fields of 35 to 140 acres. The soils are mostly sandy.

Fifty-four pivot irrigation rigs spray chlorinated, treated wastewater onto circular fields of 35-140 acres, primarily planted in corn.

No specific facilities monitor the leachate from the sanitary landfill zone. However, an extensive monitoring system is used to sample surface and groundwaters associated with the storage and irrigation operations. Around the wastewater treatment system, 29 surface water stations are monitored monthly, 30 seven-well sets south and west of the lagoon dikes are monitored daily.

Monitoring protocol includes analysis of three water quality parameters. Evidence after two full years of operation suggests that removal of BOD and SS and phosphorus is 98%, and nitrogen is 70%. No virus or coliform organisms are recorded in the final outfall. Lagoons have a designed leak rate, but that water is intercepted and returned. Presumably some nitrogen removal by denitrification is accomplished through this process.

After two years of operation at Muskegon, removal of BOD and SS and phosphorus is 98%, removal of nitrogen is 70%.

While operating costs for the first year ran to about $40 per 10 million gal processed, it is felt that crop revenues will reduce this cost in the future. More than a quarter million bushels of corn were harvested in 1975. Predicted crop income was between $240,000 to $360,000 a year but reached $330,000 in the first year, $700,000 in the second year and is estimated at $1 million for 1977. The sale of corn reduced the $1.9 million operating cost for wastewater treatment during 1975 by about one-third. Nitrogen fertilizer was injected into the wastewater daily during the active part of the corn growing season (2 months) to increase corn growth and yield and to stimulate increased removal of phosphorus, potassium, and other wastewater nutrients. From 0 to 89 pounds per acre of nitrogen fertilizer was added to the different irrigated fields, depending upon the amount of wastewater applied and corn crop's needs.

Sale of corn irrigated with wastewater at the Muskegon site reduced operating costs by 1/3 in 1975.

Crops are grown and sold for animal consumption. Crops are grown in circular areas of from 1500 to 2800 ft in diameter, with some overlap in places. Spray is from center pivot rigs rolling on pneumatic tires. Head pressure is 35 psi with 10 psi nozzle pressure. This provides a raindrop effect rather than a fine spray, providing better groundwetting and less aerosol effect. The maximum application rate is set at 4 in/wk

but presently averages about 2.1 in/wk. The approximate application loadings of NO_3^- and PO_4^{-3} are 150 lb/acre-yr and 50 lb/acre-yr respectively.

Average yields on 5,000 acres of corn irrigated with wastewater increased from 60 bushels per acre in 1975 to 81 bushels per acre in 1976. This increase occurred despite dry weather in 1976 which reduced the county average from 65 to less than 50 bushels per acre. The estimated increase in income from sale of corn kept pace with dramatically higher energy costs, so that the operating costs in 1976 (including debt retirement) remained about equal to the 1975 treatment cost of 24c per thousand gallons of wastewater. Table 6 summarizes the increased corn yield and income at Muskegon County's Wastewater System.

Table 6. Increased Agricultural Productivity by Renovation/Reuse of Wastewater in Muskegon (EPA, 1976)

	Corn Yield & Income		
	1974	1975	1976
		bu/acre	
Wastewater Site	28	60	81
County Average	55	65	45-50
Gross Crop Revenue ($X10^6$)	0.35	0.7	1.0(est.)

A careful examination of data from a three-year study has shown that diversion and treatment of wastewater flows have brought about significant improvements in water quality in Mona and Muskegon Lakes. Such improvements, and the likelihood that pollutant levels in surface streams

and lakes will decline further with time, have important implications for new recreational and industrial developments in the community. Muskegon County has established an office for planning and developing these new potentials. In 1976, several industries selected Muskegon as the site for new operations. The County's wastewater treatment system was an important factor in their decision.

Initial operating difficulties have been irritating, but not major. It is felt that the basic design is sound and the system should perform to all expectations. Specifically, that means serving the needs of a population of 170,000 by 1992 and providing wastewater renovation equal to or in excess of then prevailing water quality standards for the entire anticipated 43.4 mgd flow.

The Muskegon land treatment system has improved water quality in Mona and Muskegon Lakes and has been a major factor in the decisions of several industries to move their operations to Muskegon.

CASE STUDY COVER SHEET

SYSTEM Dan Region Project (Preliminary study at Ashqelon) (Name) (Date started)

LOCATION Tel Aviv, Israel A. Amramy (Person involved)

FACILITY DESCRIPTION Municipal (waste classification) rapid infiltration (application system(s))

APPLICATION (rate) 2-3 day wetting 7-9 day rest (schedule)

CROP(S) none

PRETREATMENT lagoons

VOLUME TREATED

WORKING YEAR 12 mo. CLIMATE ZONE arid, similar to Zone B.

SOIL Sand dunes

COST

LAND AREA 0.75 acre

STORAGE CAPACITY

COMMENT: A demonstration/feasibility-research project 31 mi south of Tel Aviv having three spreading beds receiving effluent from lagoons. Only the first 4 in. of sand experienced organic matter buildup. Sand 10-23 ft overlies clay and, on percolation, total dissolved solids remain unaltered, suspended solids were reduced a little, DO, BOD, COD were reduced. Fe, Mn, and NO_3^{-1} were significantly increased. Bacterial content remained high. Water was not potable.

REFERENCES: Amramy, A. 1968. Re-use of municipal wastewater. Civil Engineering. May. 58-61.

Dan Region Project
(Preliminary Study at Ashqelon)
Tel Aviv, Israel

This is a demonstration project testing the feasibility of using infiltration-percolation of municipal wastewaters through sand dunes to achieve water purification adequate for reuse. A comparatively small test plot was selected because of its availability, and three spreading basins were constructed, each of 0.25 acres. Effluent from three small anaerobic lagoons passed in series through a semi-aerobic and an aerobic lagoon before land treatment.

Pretreated wastewater was flooded onto sand dunes underlain with clay layers of low permeability at the Dan Region Project in Israel.

The soil chosen for this pilot study was considered inadequate, but it was the only site available. Subsoil layers under the sand dunes consisted of clayey materials of low permeability. Conditions for optimal operation were found by trial and error to be 2 to 3 days of wetting followed by 7 to 9 days of drying, working on a 10-day cycle. Surface clogging was severe but was relieved as a result of the drying period.

Observation wells around the site were monitored for changes in water quality and hydraulic conductivity. Clay swelling reduced hydraulic conductivity, causing considerable groundwater mounding beneath the infiltration basins.

During passage through the 1 to 23 ft of sand and to a depth of some 262 ft to the aquifer, the BOD was reduced 90% (from 28.4 mg/l), COD from 58% to 90% (from 193 mg/l), and organic nitrogen about 63% (from 6.5 mg/l). The pH changed from 8.0 to 8.5 for the lagoon effluent to 7.3 to 8.7. Calcium content of groundwater increased markedly (about 130%), indicating ion exchange between water and the soil, but no specific soil analysis was reported. Only the top 10 cm (4 in.) increased in organic matter content; there was no organic build-up in the lower levels.

The percolated water was odorless, clear, and without unpleasant taste, but was too high in dissolved Fe, Mn and detergents to meet U.S. Public Health Service standards for potable water. Nitrogen "breakthrough" was observed and thought to be caused by the periodic "unloading" of the ammonia previously adsorbed by the soil, followed by its oxidation into nitrates.

Percolate at the Tel Aviv project was too high in dissolved Fe, Mn, and detergents to meet U.S. Public Health requirements; nitrogen breakthrough occurred.

It was decided that in future work percolation would have to be through longer distances of 2,600 to 4,900 ft of this type of sand and for longer periods of time such as 400-2000 days before attempting recovery. To be safe, reclaimed waters would then be mixed with water from other sources in a 2:1 ratio before being delivered for general reuse.

CASE STUDY COVER SHEET

SYSTEM Campbell Soup Company (Name) — 1961 (Date started)

LOCATION Napoleon, Ohio — P. T. DuByne (Campbell Soup Co.) (Person involved)

FACILITY DESCRIPTION Cannery (Tomato) (waste classification) — Overland flow (application system(s))

APPLICATION 1.2-1.4 in./day (rate) — spray 6 hrs, rest 6, on 24 hr schedule (schedule)

CROP(S) Reed canary, seaside bent, red top

PRETREATMENT screened

VOLUME TREATED 5.20 mgd

WORKING YEAR 50 day CLIMATE ZONE D

SOIL clay, clay loam

COST

LAND AREA 165 acres

STORAGE CAPACITY none

COMMENT: A tomato soup cannery which sprays screened effluent onto five graded slopes. Renovation is by overland flow and some infiltration; discharge is to nearby river. Average COD load is 916 mg/l, BOD is 548 mg/l, organic-N is 26.8 mg/l and pH ranges from 4.9-9.3.

REFERENCES: Bendixen, T. W., R. D. Hill, F. T. DuByne, and G. G. Robeck. 1969. Cannery waste treatment by spray irrigation-runoff. J. Water Poll. Contr. Fed. 41(3)-part 1: 385-391.

Urban, D. R. 1963. Evaluation of the soils resources, Campbell Soup Farm, Napoleon, Ohio. Conserv. Farming Guide. Soil Conserv. Dist., Defiance, Ohio.

Campbell Soup Company
Napoleon, Ohio

At Napoleon, Ohio effluent from screened tomato wastes is sprayed from fog nozzles or spray nozzles at the top of 5% slopes; wastes are filtered through 165 acres of natural subwatersheds and ultimately discharged to a nearby river.

The Campbell Soup Company of Napoleon, Ohio began using a complete containment spray irrigation system in 1954, and gradually evolved into a spray irrigation-overland flow system. The present system utilizes five natural sub-watersheds ranging from 11 to 56 acres in size, for a total area of 165 acres. Each watershed is graded to uniform 5% slopes. The slopes are divided with collection waterways to provide slope runs of 100-200 ft. One sub-watershed retains remnants of an old tile underdrainage with five outlets. Effluent of screened tomato wastes is sprayed from fog nozzles (14-20 gpm) or spray nozzles (7-25 gpm) at the top of the slopes and ultimate discharge is to a nearby river.

Soils are calcareous clay or clay-loam till, outwash, and river alluvium that is underlain by black shale at about 50 ft. Infiltration rates are fairly high but subsurface permeability is low, giving "imperfect" to "very poor" natural drainage. Agricultural soils of the area are generally underdrained. Other soil characteristics are not specified. The estimated fate of the hydraulic load is about 40% to runoff, 30% to evapotranspiration, 25% stored in the upper 3 ft of soil and eventually percolated to greater depths, and about 5% is lost directly by spray drift/evaporation. A schematic diagram of this system is given in Figure 10.

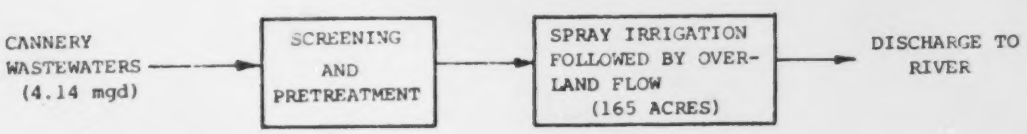
CANNERY WASTEWATERS (4.14 mgd)
SCREENING AND PRETREATMENT
SPRAY IRRIGATION FOLLOWED BY OVERLAND FLOW (165 ACRES)
DISCHARGE TO RIVER

Figure 10. Schematic flow diagram of the land application system for wastewater treatment employed by the Campbell Soup Company of Napoleon, Ohio.

Water renovation is monitored to some extent, but how much is standard routine and how much was unique to the research effort is unclear. Waste removal on a mass basis was: COD, 81-95%; BOD, 98.7%; Total-N, 73-93%; phosphates, 65-84%; and suspended solids, 89-97%. In all cases, the underdrained slope outperformed other slopes. The water quality from the runoff area was compared to the quality of runoff from agricultural watersheds as given below:

Table 7. Water Quality Comparisons. Data from Two Watersheds, Campbell Soup Company, Napoleon, Ohio. (Bendixen, et al., 1969).

Item	Agricultural Watershed lb/acre-yr	Spray-Runoff Watershed lb/acre-yr
COD	480-1300	410-2080
Total-N	11- 237	18- 72
PO_4^{-3}	1- 28	11- 54

Conversion factors: lb/acre-yr x 1.12 = Kg/ha-yr

The overland flow treatment system at Napoleon's Campbell Soup plant was substantially improved in 1973 based on experience gathered at the company's plant in Paris, Texas. Table 8 gives a comparison of the characteristics of the original system and of the improved system.

Land utilization at the Napoleon treatment system was increased by investing approximately $300 per acre in earthmoving. In this way the wetted area was increased to 80%. The land utilization at Napoleon formerly was about 35%. Available land must be utilized efficiently in this area because land values are exceeding $1,000 per acre and the piping of the disposal system adds another $700 to the costs.

Wastewater renovation was enhanced by increasing the wetted area to 80% at the Napoleon site by earthmoving.

Table 8. NAPOLEON, OHIO PLANT
CHARACTERISTICS OF SPRAY SYSTEM - INITIAL DESIGN

1961 - 1965

	Volume Sprayed*		Volume of Runoff		COD Applied		COD of Runoff			
	mil gals	gal/ acre-day	mil gals	% Flow	mg/l	1000 lbs.	mg/l	%Red.	1000 lbs.	%Red.
1961	152.3	19,700	86.5	57 (29)**	576	732.6	94	84	67.7	91
1962	158.2	18,800	99.9	63 (36)	523	691.5	81	85	67.6	90
1963	203.0	27,900	86.6	43 (36)	369	625.5	94	75	67.8	89
1964	208.1	23,400	84.0	40 (29)	661	1208.0	136	79	95.3	92
1965	316.7	32,500	152.6	48 (26)	500	1319.3	94	81	119.9	91

CHARACTERISTICS OF SPRAY SYSTEM - IMPROVED DESIGN BASED ON PARIS

1973 - 1976

					BOD Applied		BOD of Runoff			
1973	211.3	16,611	97.5	46.2	430	757.8	11.0	97.4	8.9	98.8
1974	182.6	17,552	67.1	36.7	458	697.5	10.1	97.8	5.6	99.3
1975	188.1	20,436	125.7	66.8	471	738.8	10.0	97.9	10.5	98.8
1976	260.8	19,622	136.7	51.3	390	848.3	5.0	98.7	5.7	99.3

*Avg. season was 50 days
**( ) Percentage after correction for rainfall

Source: Gilde, Date Unknown.

CASE STUDY COVER SHEET

SYSTEM Flushing Meadows Project (Name) — 1967 (Date started)

LOCATION Phoenix, Arizona — H. Bouwer (Person involved)

FACILITY DESCRIPTION Municipal (waste classification) — rapid infiltration (application system(s))

APPLICATION Average 1-2 ft/day application (rate) — mixed for research purposes (schedule)

CROP(S) Bermuda grass, Mexican "sprangle top", barnyard grass

PRETREATMENT activated sludge

VOLUME TREATED average 0.67 mgd

WORKING YEAR 12 months CLIMATE ZONE B

SOIL fine loamy sand over coarse sand

COST Estimated $5.00/acre foot

LAND AREA 2 acre

STORAGE CAPACITY none

COMMENT: Pilot study and feasibility demonstration on the bank of the dry Salt River bed. Six parallel infiltration beds, 700 ft x 20 ft, with ground water at 10 ft, were inundated at schedules ranging from 2 days flood, 3-5 days drying to 2 to 4 weeks each. Renovated water was pumped to surface storage for recreational and industrial reuse. Denitrification was relied upon for nitrogen removal.

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Flushing Meadows Project

Nitrogen removal is highly dependent on application schedules. Nitrogen loadings range from 24,000 to 32,000 lbs/acre-yr. far more than could be taken up by crops, so removal depends on anaerobic denitrification, achieved by flooding. However, to facilitate mineralization of organic-nitrogen, and allow conversion to NO^-_3, "resting" periods must be programmed so that the needed soil aeration would occur before inundation. Trial and error methods suggested that a 14 day wet, 10 (summer) or 20 day (winter) dry schedule reduces total N to about 30-60% of influent concentrations and NO_3-N to near zero except at the start of inundation. That anomaly at the start of inundation occurs, it is felt, because water held by the soil during dry periods becomes aerated, NH^+_4 is oxidized to NO^-_3 and, on inundation, that NO^-_3 is flushed out too rapidly for any denitrification to occur. Over a period of years it was found that alternating application periods from long to short and back again was not only most effective but necessary to keep soil C.E.C. from becoming saturated with NH^+_4.

Filter basin clogging occurred with application schedules involving 2-3 weeks of continual flooding or when suspended solids rose to 50-100 mg/l during the winter. Severe clogging was remedied by "shaving off" the filter beds each spring.

23rd Avenue Project Based on Flushing Meadows Results

The 23rd Avenue Project, a large scale rapid infiltration system, was designed based on engineering criteria developed at Flushing Meadows. This 40-acre project was constructed in 1974. It was necessary to supplement the present water resources in the Phoenix area, and the 23rd Avenue Project was intended to demonstrate the feasibility of rapid infiltration on a scale that could partially meet this need for water. If initial demonstration

The 23rd Avenue Project is a large scale rapid infiltration project in Phoenix intended to demonstrate the feasibility of economically renovating all effluent discharged in Phoenix area, making it available for reuse for nuclear power plant cooling, irrigation, and development of aquatic parks.

project shows that wastewater can be economically renovated, the system could be expanded to reclaim all of the effluent discharged in the Phoenix area. A significant portion of the treated flow would be used for nuclear power plant cooling water. The rest could be made available for irrigation and an extensive aquatic park development.

The new rapid infiltration site is located on the north side of the bed of the Salt River and east of 35th Avenue. Secondary effluent from the 23rd Avenue wastewater treatment plant flows through a concrete channel to the site. The soil profile at the site is similar to the Flushing Meadows site, consisting of loamy sands, sand, gravel, and boulders to a depth of more than 200 ft. On the basis of results learned at Flushing Meadows, infiltration rates of at least 2.5 ft/d were expected.

When the 23rd Avenue Project is fully operating, about 13 MG per day secondary effluent will be applied to the four rapid infiltration basins. The renovated water will be recovered by a series of three 24-in diameter wells equipped with electric driven pumps of 3000 gal/min capacity. Two 6 in diameter observation wells and sampling wells have been built, these to be used to sample renovated water quality and monitor the groundwater level. The project will be operated so that the groundwater level will be the same as that in the aquifer adjacent to the project to prevent the movement of renovated water away from the site.

In addition to the quality and level of groundwater, the direction of groundwater movement will also be checked by monitoring the total dissolved solids concentration in the observation wells. If no native groundwater enters the project, the total dissolved solids of the reclaimed water should be approximately the same as that of the wastewater effluent.

A special objective of the 23rd Avenue Project is to determine how air pressure buildup in the soil beneath large infiltration basins affects the infiltration rate. The effects of high algae loading on surface clogging will also be studied.

A special objective of the 23rd Avenue Project is to determine how air pressure buildup in soil beneath large infiltration basins affects the infiltration rate.

Research at Flushing Meadows has dealt with the fate of viruses in wastewater as they enter the soil. However, the emphasis of the most recent research at Flushing Meadows is aimed at maximizing nitrogen removal. Increased nitrogen removal has been realized by reducing the hydraulic loading rate to the basins and using optimum flooding and drying periods. Preliminary results indicate that by reducing the annual hydraulic loading to the basins from 300 ft to 173 ft, nitrogen removal increased from 30% to 60% and phosphate removal increased from 70% to 90%. The application schedule was 9 days flooding and 12 days drying.

CASE STUDY COVER SHEET

SYSTEM Padre Dam Municipal Water District (Name) — 1959 (Date started)

LOCATION Santee, California — Edwin W. Houser (Person involved)

FACILITY DESCRIPTION Municipal waste (waste classification) — slow percolation, lakes (Application system(s))

APPLICATION flood (rate) — (schedule)

CROP(S) naturally occurring chaparral, sycamore trees in percolation area

PRETREATMENT tertiary, chlorinated

VOLUME TREATED 3.6 mgd

WORKING YEAR 12 months CLIMATE ZONE A

SOIL clay, sand, gravel

COST $2,224,944

LAND AREA 3-acre percolation area, 100-acre recreation area

STORAGE CAPACITY 22 MG

COMMENT: The Santee project represents a deliberate attempt to convert municipal wastewater to water suitable for recreation. Chlorinated secondary effluent is filtered through sand before passing in a series through three abandoned gravel pits converted to lakes. The system now includes seven recreational lakes representing 75 water surface acres and 25 ground acres. Boating and fishing are allowed. A golf course also uses the reclaimed water for irrigation and water hazards. The system has become a major source of fresh water for recreation in this semi-arid region.

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Padre Dam Municipal Water District
Santee, California

The Padre Dam Municipal Water District is a public agency which provides water and sewerage service for the unincorporated community of Santee, California. The District has no local water supply and must depend on water from the Colorado River, some 300 miles away, and from the Feather River which is part of the California State Water Project. The customers of the District currently use 8,000 acre feet of water per year. The wholesale cost of this imported water has more than quintupled in the past 20 years from $17 an acre foot in 1957 to $90 in 1977. It is expected to increase further during the next decade to a price of more than $190 per acre foot.

The Padre Dam Water District aims to reclaim water from sewage and reuse it primarily for recreational purposes thus reducing the amount of expensive "imported" water purchased.

The intention of the water district is to reclaim water from sewage and reuse it for recreational, agricultural and industrial purposes, thus reducing the amount of expensive imported water purchased. The major difficulties faced were acquiring appropriate land and assuring public acceptance of reclaimed wastewater for recreational use. According to water district officials, the project has been successful because of a "fortuitous governmental cooperation, dedicated employees and good management". A former manager of the Water District said, "One reason the project has been so enthusiastically accepted by our community is because we have always tried to be completely honest with the people and have kept them informed throughout the progress of the project." Public acceptance was achieved through several tactics. A major public education campaign was conducted both in the immediate community and in surrounding communities for considerable distances. The lagoon site and all other parts of the system were landscaped, seeded with grasses, and made attractive. Picnic tables were installed, the grounds were mowed, and swans were purchased to live at the site. Access roads were opened. However, the immediate water area was securely fenced to prohibit entrance by the public. People could still come, see, smell, and appraise

Public acceptance of using reclaimed wastewater for recreation was achieved through a gradual, conservative public education campaign.

the facility from the other side of the fence. A public protest arose; citizens demanded access to the attractive recreational facility, but authorities assured the public that there would be no public access until the health safety could be guaranteed. This conservative approach helped to build public confidence in the safety of the project.

The potential hazard of the operation was evaluated by the Santee County Water District in conjunction with the U.S. Public Health Service, the California Department of Public Health, and three other state and county agencies. This effort provided the necessary information, including proof of virus removal, that assured the safety of the waters. Gradually and systematically, the lakes were opened to public boating (1963), fishing (1964) and swimming (1965). Although swimming was allowed for five years, the high degree of chlorination caused the build-up of iron and manganese in the water. Special devices were purchased to filter out these elements. When the filtering devices wore out after five years, the water officials decided to close the swimming area rather than to purchase new equipment.

The Padre Dam system is based around abandoned sand and gravel pits underlain by an impervious layer of clay. These three nearly depleted sand pits, very near the new municipal treatment facility, were found to be suitable for surface storage. Ownership of the pits was transferred to the sanitation district. The pits were bulldozed to form three basins.

The Padre Dam system is located in a natural shallow canyon, its bottom covered with sand and gravel.

The systen is located in a natural canyon, shallow with gently sloping sides. The canyon bottom is covered with an alluvial fill of sand and gravel approximately 12 ft deep and ranging from 400 to 1000 ft in width. An impervious clay underlays the sand and gravel. The effluent distribution system extends into San Diego River basin. The raw

sewage pump station is located at the mouth of the canyon. Raw sewage from this district of about 30,000 people is pumped up the canyon, past the recreational lakes, percolation basins, and oxidation ponds to the treatment plant. The effluent, after treatment in the activated sludge plant, flows back down the canyon through oxidation ponds and percolation basins, and thence is filtered through natural underground aquifers into the recreational lake system from which effluent for distribution is pumped. A schematic of this system is shown in Figure 11.

The pump station is a three level structure, each pump capable of delivering 4,150 gallons per minute against a head of 192 feet. The basic treatment used at the plant is activated sludge with a design capacity of 4.0 mgd in the first stage. The elements of the treatment system are primary sedimentation, biochemical oxidation by aeration, final sedimentation, polishing in three oxidation ponds, and then percolation through the soil a minimum of 400 feet. Sludge and excess wastewater are sent to the San Diego Metropolitan System.

Wastewater reclaimed for recreational lakes in Santee is chlorinated at four points before being discharged into lakes.

Chlorination is provided at four points: to the raw sewage influent, return activated sludge, effluent recovery water at the wet well, and final effluent. Chlorine is applied to raw sewage for odor control, to the sludge to control bulking, and to the effluent to provide disinfection as required for public health purposes.

There is a total of 11 percolation basins which measure 50 ft by 150 ft by 3 ft each. Water is now percolated through the soil a minimum of 400 ft down into sand and gravel, and because of the underlying clay it moves horizontally in a downstream direction until it emerges into an interceptor trench located above the uppermost lake. From the trench, water flows in a downstream direction until it reaches the lake adjacent to the oxidation pond. Eventually the hydraulic capacity of

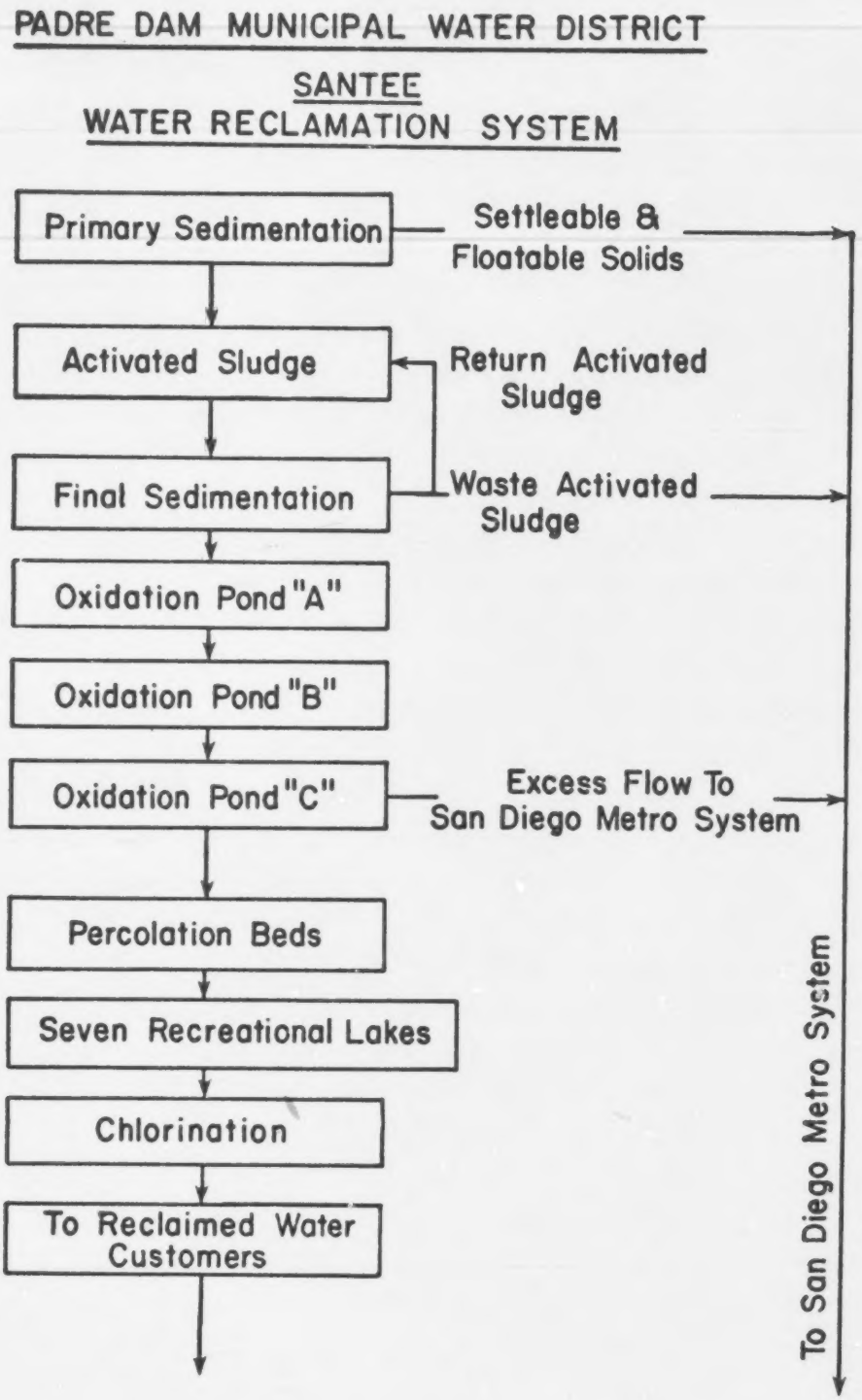

Figure 11. Schematic flow diagram of the land application system for wastewater treatment of the Padre Dam Municipal Water District in Santee, California.
Source: Padre Dam Municipal Water District, 1977.

the percolation area will be exhausted, and it will be impossible to percolate greater volumes of water in the future. This contingency has been provided for and tertiary treatment facilities will go into operation to accomplish the full treatment job within the plant site, thereby eliminating the need for an oxidation pond and soil percolation.

When the hydraulic capacity of the percolation basins is exhausted, tertiary treatment facilities will take over for the percolation basins and oxidation pond.

A laboratory on-site provides facilities to perform all necessary chemical and bacteriological tests for proper control of the operation and of water quality in the recreational lake system.

The surface water of this system continues to be monitored weekly. The final effluent contains 18 mg/l BOD, 25 mg/l SS, 19 mg/l P, and 22 mg/l NO_3^-. No monitoring wells, however, are used despite a 3 to 4 ft depth to the water table.

Extensive studies have been conducted at the Santee site on viruses, bacteria, phytoplankton, benthic organisms, and fish. Further research projects have been proposed including the creation of a live stream using reclaimed water, and energy-saving alternatives for reclamation of water. Among the other proposals are using reclaimed water for drip irrigation, for pet food production, for coastal wetlands, and for irrigation of saline-tolerant plants in San Diego County. Among the new technologies the group proposes to investigate are: efficiencies of different aquatic vascular plants in wastewater treatment systems, models for the most cost effective systems of brine disposal after demineralization in inland communities.

Officials of the Padre Dam Municipal Water District plan to do extensive research in a number of areas on reclaimed wastewater including creation of a live stream using reclaimed water.

CASE STUDY COVER SHEET

SYSTEM HYDIG (Name) 1952 (Date started)

LOCATION Hertfordshire, England

FACILITY DESCRIPTION Municipal sludge (waste classification) Spray irrigation, surface spreading from stationary tank and trucks (application system(s))

APPLICATION _____ (rate) (schedule)

CROP(S) grass, forage crops, English black beans, grains, potatoes, other root crops.

PRETREATMENT secondary

VOLUME TREATED 37 mgd

WORKING YEAR 12 months CLIMATE ZONE similar to C

SOIL gravel, easily drained

COST U.S. $6.00/1000 gal.

LAND AREA 6000 acres

STORAGE CAPACITY _____

COMMENT: A population of 550,000 is served by secondary treatment facilities. The sludge from that treatment is applied onto 1000 acres of public land and some 5000 acres of farm land. The sludge is called HYDIG for public relations purposes. No odor, fly or health problems are noted. Toxic element loading is considered to be the rate limiting factor and is restricted to 8.3 mg/l zinc equivalent per year throughout the 30 year site lifespan.

REFERENCES: Seabrook, B. L. 1974. Irrigation of liquid digested sludge. Movie, Wealth from Waste, Hertfordshire, England. Fact sheet for U.S. EPA Office of Water Program Operations, Washington, D.C. Aug. 30.

HYDIG
Hertfordshire, England

The West Hertfordshire Main Drainage Authority, located at Rickmansworth, about 20 miles north of London, England, serves an area of 210 square miles with a population of 550,000. 141,000 cubic meters/day (37 mgd) of wastewater, 80% from domestic sources, is treated in a two-stage treatment facility. Only 3% of the waste appears, ultimately as sludge, and that is applied to land. To avoid public reference to sewage and its connotation the digested sludge has been given the name HYDIG.

The primary and activated sludges are held in anaerobic digestion tanks for 20-24 days at temperatures of 90-98°F. The annual production of digested sludge amounts to about 90 million gallons. The production of digested sludge is continuous; some sludge is irrigated every day except Sundays. The daily application is approximately 1/24 of the contents of the digestion tanks, or from 250,000 gallons to 500,000 gallons (all volumes are given in U.S. gallons). Capacity of the secondary sludge storage tanks is approximately 8 1/2 million gallons, which permits winter storage up to 6 weeks.

About 90 million gallons per year of liquid digested sludge is produced. The sludge has a solid content of about 3% and is applied to the land, either by spreading from tank trucks or by irrigation from pits or stationary storage tanks adjacent to the fields. Approximately 1000 acres are owned by the Authority and used as experimental farmland, and the balance of the 6000 acres is operated or owned by some 62 private farms. The cost of transporting and applying HYDIG in 1972 was about $6 per 1000 U.S. gallons. The disadvantages of tank truck operation are more than offset by the savings that result from having neither investment in 5000 acres of privately owned farmland nor farm operating expenses on this land.

90 million gallons of digested sludge is applied to the land each year at this site 20 miles north of London; sludge is spread from tank trucks or irrigated from pits or stationary storage tanks adjacent to the fields at a cost of $6 per 1000 U.S. gallons.

The irrigation is done on gravel soils that are fairly firm and easily drained. The crops grown include grass, forage crops, English black beans, grains, potatoes and other root crops. There have been no build-up of toxic salts, cattle disease, objectionable odors, fly problems, nor community objections. The public health officers are satisfied that the Hertfordshire irrigation procedure is not a threat to public health. There have been some individual complaints, but the majority of these have involved the use of the highways by the large tank trucks. So far as is known, there has been no significant detectable uptake of trace metals in any of the crops grown at Hertfordshire. The principal problem appears to be speculation about what might happen after decades of sludge application. There is some concern that long term loading of sludges may produce concentrations of toxic elements in soils that will prove to be hazardous to crops. However, if crops such as certain grasses are used which tolerate the trace metals involved, the problem may be minimized. The most abundant toxic metals are zinc, copper, and nickel.

There has been no buildup of toxic salts, cattle disease, objectionable odors, fly problems, community objections, nor significant detectable uptake of trace metals by crops grown at Hertfordshire. The main problem is speculation over long term effects of sludge application and concentrations of toxic elements in soils.

Tentatively, the Authority allows no more than 250 ppm of zinc-equivalent to build up in the topsoil of previously unamended soils over the site lifespan. It is recognized that the toxic element build-up appears to be cumulative, so the Authority has selected a 30-year period for the application of sludge to a particular piece of land. This limits the annual dressing to no more than 1/30 of the 250 ppm arbitrary maximum. A further requirement is that soil pH must be maintained at ≥ 6.5 at all times. It has been found that when the soil pH is less than 6.5 toxic effects of certain elements are accelerated. As a general precaution, livestock are not allowed to graze fields to which sewage has recently been applied until after rain has washed the edible plant

sections clean. The Hertfordshire Authority points out, however, that there is no evidence to show that there has even been a problem from ingestion of such metal traces when livestock have grazed on fields that have not been washed clean by rain. In fact, palatability tests have led to observations that the cattle feed avidly upon grass which has received a fresh application of liquid digested sludge.

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